Hazard Identification for Human and Ecological Effects of Sodium Chloride Road Salt

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July 6, 2007

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FINAL

I-93 Chloride TMDL Study:

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ABSTRACT

The New Hampshire Department of Environmental Services (DES) requested an evaluation of the human and ecological risks associated with the application of sodium chloride (NaCl) road salt to roadways. NaCl is the major de-icing agent used in NH to mitigate ice-related accidents. However, it may also threaten the integrity of human and ecological health. This paper presents a synthesis and interpretation of available literature on the effects of both sodium chloride road salt, including those of the sodium cation and chloride anion in the dissolved phase, on humans, wildlife, aquatic life, and vegetation. The assessment addresses the routes by which receptors may be exposed and the exposure thresholds that induce toxicity. Such information is used to determine that the State's current chloride water quality standard of 230 mg Cl^-/L is adequate and thus should be used as the appropriate target for TMDL studies.

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1.0 Introduction

The New Hampshire Department of Environmental Services (DES) has requested preparation of a white paper to evaluate the human and ecological risks associated with sodium chloride (NaCl) road salt and its sodium cation and chloride anion. The utility of NaCl as an effective de-icing agent is well known and promoted. De-icing chemicals work by lowering the freezing point of water. This paper presents a synthesis of available information on the fate and transport and the resulting ecological risk associated with this agent in New Hampshire waters. Peer-reviewed literature and grey literature from other states and provinces form the basis of this investigation.

The predominant salt used as a deicer in North America is NaCl, which is approximately 40% sodium and 60% chloride by weight. Trace elements may include phosphorus, sulphur, nitrogen, copper, and zinc (EC, 2001). NaCl typically derives from mined rock salt that has been crushed and screened to a mixture of three-eighths inch granules to fine crystals. In addition, to prevent caking of the salt, this mixture is often treated with additives containing cyanide (MPCA, 2000).

2.0 Fate and transport

Table 1 summarizes key properties of NaCl that influences its fate and transport, which determine its potential exposure to human and ecological receptors. The eutectic temperature is the lowest temperature at which the substance will melt ice, whereas the working temperature is the lowest effective de-icing temperature (EC, 2001). Its high solubility renders it very mobile, while its particle density makes it sink to the bottom of a surface waterbody. Its vapor pressure and Henry's Law constant indicate that it does not volatilize from air or water and moist soil surface. However, it may associate with suspended particulate matter or water droplets (USEPA, 2003a).

Table 1 Properties of NaCl Road Salt

CAS No.	7647-14-5
Molecular Weight	58.44 g/mol
Eutectic Temperature (°C)	–21
Working Temperature (°C)	0 to –15
Water Solubility (g/L)	357 at 0^{o} – 25^{o} C
	391.2 at 100^{o} C
Melting point	800.8^{o} C
Color	White
Odor	Odorless
Specific gravity	2.165
Density	> 1 ton per cubic yard
Vapor pressure at 865°C	0.1 kPa (1 mm Hg);
Henry's law constant at 20°C	K = 1211 Pa, 1/H = 4.3×10^{5}

(EC, 2001; Salt Institute, undated; PMRA, 2006)

Changing ice or snow into water requires heat from the air, the sun, the pavement, or traffic friction. The degree to which road salts may have an impact on the surface water and groundwater environments varies significantly, depending on the road salt loading, climate, surface and subsurface soil conditions and location of the site within the overall hydrogeological environment.

Where there is not enough moisture, salt that has not dissolved may migrate via air currents, facilitated by traffic motion. Another route, however, is that wildlife will ingest the solid salt or it will accumulate on vegetation.

Still, one of the primary concerns associated with NaCl road salts is their high solubility in water. Impervious surfaces, such as roadways and parking lots, and saturated soil lead to overland flow, which migrates to surface water, such as streams, wetlands, and lakes (EC, 2001). Salt may also be intercepted by vegetation, the toxicity of which is discussed in Section 5. Sections of roadways with curves as well as areas of many cracks and crevasses in the pavement may also accumulate salt (Mineau and Brownlee, 2005).

Some of the precipitation with the dissociated salt ions will percolate through the shallow soil, moving laterally as it moves downward through the vadose zone to the water table. The presence of salt migrating through the soil may increase the soil density as the soil accumulates in the pores, thereby reducing permeability. Evapotranspiration may retard this interflow of contaminants. The amount of precipitation with NaCl that reaches the water table depends on a number of factors, including the duration and intensity of the precipitation event, the initial soil moisture content and the soil moisture characteristics (TRD, 1991). Once below the water table, the migration of sodium and chloride ions depends on several other physical and chemical processes including mechanical dispersion, molecular diffusion and density effects. The migration rate of chloride ion will be the same as that of the water. This is not the case for the sodium ion, which is influenced by cation exchange reactions (TRD, 1991). For example, sodium ions are exchanged with calcium adsorbed to clay-rich materials, thereby decreasing the sodium ion concentrations within the infiltrating groundwater.

Chloride circulates through the hydrological cycle via mostly physical rather than chemical processes. The chloride ions pass readily though soil, enter groundwater and eventually drain into surface waters. Because chloride ions are persistent and are trapped in the hydrological cycle, all chloride ions applied to roadways as road salts or released from patrol yards or disposal sites ultimately reach surface water (EC, 2001).

Dilution with increased rates of recharge to groundwater decrease chloride groundwater concentrations. Typical concentrations of chloride in water depend on the type of water, with freshwater lakes averaging 0 to 100 mg/L and seawater averaging approximately 20,000 mg/L. However, chloride concentrations in freshwater following salt application have been reported greater than 10,000 mg/L. Such extremes were observed near large roadside snowbanks, and were fortunately diluted such that adjacent streams contained only 45 mg/L (TRD, 2001). Dilution effects are even greater for larger rivers.

NaCl has altered the biogeochemistry in surface waters in two accompanying mechanisms. First, as sulfate (SO_4^-) concentrations in surface waters have declined since the 1980s, NaCl has provided more chloride as an alternative mobile anion, thereby influencing soil base cation leaching. Second, sodium migrating through the soil can exchange with other cations, such as Ca^{+2}, Mg^{+2}, K^+, H^+, and Al^{+3}. These exchanged cations are then mobile and migrate with the groundwater to surface water, leading to their increases concentrations there. The acid neutralizing capacity (ANC) of a surface waterbody depends on the sum of the major base cations, particularly Ca^{+2} and Mg^{+2} (Rosfjord *et al*., 2007). As such, by shifting a surface water's ANC, NaCl reduces the ability of that surface water to buffer acid deposition.

Although anti-caking agents are not in the crystalline salt that homeowners use on sidewalks, the salt applied to roadways includes anti-caking agents that contain cyanide. Without the anti-caking additives, salt crystals congeal into chunks impossible to spread on the roadways. Certain bacteria break down the additives in road salt, releasing free cyanide into the environment. The additives can also photodegrade in sunlight, thereby releasing cyanide.

3.0 Human health impacts of NaCl

EPA has set a secondary maximum contaminant level (SMCL) for sodium of 250 mg/L based on organoleptic issues, i.e., it compromises the taste of the water. However, for drinking water, EPA now requires monitoring and has set a drinking water limit of 20 mg/L for sodium above which public water systems must report the concentration to local health authorities (USEPA, 2003a). Such reporting allows physicians to advise any of their patients on sodium-restricted diets accordingly. Excess sodium, linked with hypertension, which is high blood pressure identified as greater than 140/90, has driven EPA's limit. This condition is of concern because, if left untreated, it can lead to cardiac disease, renal disease, hardening of the arteries, eye damage, and stroke. Approximately 25% of the adult US population has hypertension (Makoff and Marks, 2004).

Cells in the human body aim to balance water intake with water losses from renal excretion, respiratory, skin, and gastrointestinal sources, processes controlled by a sodium-modulated channel. This balance is salt homeostasis. Hypernatremia dehydrates the cells due to the osmotic pressure of the excess extracellular sodium extracting water from the cells. Dehydrated cells immediately try to counteract the resulting shrinkage and osmotic force by transporting electrolytes across the cell membrane. An hour later, cells generate organic solutes inside them to try to restore cell volume and avoid structural damage. While generalized and pulmonary edema, which is swelling of tissues, ensues if water replacement occurs faster than water excretion or metabolism of accumulated solutes, cerebral edema is a principal symptom of cellular dehydration. The central nervous system impacts may be exhibited by convulsions, confusion, and coma. Severe cell shrinkage and stretching may cause intracranial hemorrhage (Stephanides, 2005; USEPA, 2003a).

At reasonably possible exposures, chloride is relatively not toxic to human health but does pose organoleptic issues. Accordingly, EPA has set the potable limit for chloride at 250 mg/L. Water concentrations exceeding this limit are rare and transient. Damage to roadside vegetation, detailed in Section 5.0, can also intensify the impacts on drinking water quality by limiting the retention and processing of pollutants transported in run-off, and by diminishing the buffer zones to groundwater sources and reservoirs.

Table 2 Sodium and chloride toxicity to human health

Contaminant	Threshold (mg/L)	Test Reference
Chloride	250	EPA Secondary Drinking Water Standard (mostly for taste)
Sodium	20	EPA advisory limit for drinking water
	250	EPA secondary maximum contaminant level

(Mattos, 2000)

4.0 Ecological impacts of NaCl Road Salt

EPA's guidance on ecological risk assessment provides that exposure and toxicity potentials of NaCl road salt, including the sodium cation and chloride anion, govern their ecological impacts. The dose or concentration that causes an effect in 50% of the tested population (ED50 and EC50, respectively) indicates the level of acute toxicity. When organism death is the effect, it is the lethal dose or concentration in 50% of the tested population (LD50 and LC50, respectively). Laboratory toxicity studies using standardized test organisms determine toxicity endpoints (e.g., LD50 or LC50 for acute toxicity and lowest observable effect level (LOEL) for chronic toxicity), while environmental fate characteristics and pesticide use data determine the expected environmental concentrations (EECs).

4.1 Wildlife

Road salt may affect wildlife, i.e., birds and mammals, due to their exposures to the salt as well as to the sodium and chloride ions. Birds often mistake the road salt crystals for seeds. Wildlife also ingest NaCl accumulated on foliage and the ions dissolved in water. Particularly high concentrations of sodium and chloride can be found in snow melt, which many animals drink to relieve thirst. Just as for humans, when sodium homeostasis fails for wildlife, symptoms occur. The renal system of birds, particularly those that are terrestrial, is not capable of dealing with excess sodium as is the renal system of mammals. The latter removes the excess sodium by increasing the filtration rate of the kidneys and decreasing the percentage of sodium that they readsorb (Mineau and Brownlee, 2005; Bollinger *et al.*, 2003). The sodium risk only represents part of the overall risk to wildlife as the chloride also may impact wildlife. The concentration of NaCl in water below which is considered safe for wildlife is 1,000 mg NaCl/L, comparable to 600 mg Cl^-/L (Nagpal et al., 2003).

Toxicity is often presented in body dosages, rather than concentrations of the source, that impact an organism. Although laboratory studies indicate that dermal exposures to NaCl do not elicit any skin sensitization reaction in humans, tests on rabbits tested did note that some exhibited slight skin irritated with acute exposures of 500 mg NaCl applied over 24 hours. Moreover, dermal exposures of NaCl result in an acute LD50 for rabbits of 10,000 mg/Kg body weight, indicating it is non-toxic at expected exposures. Likewise, oral and inhalation routes for rats yield an acute LD50 of 3000 mg/Kg and 1-hour LC50 of 42,000 mg/L, respectively (Bollinger et al., 2005).

A laboratory study reported that the house sparrow exhibited an LD50 of 3000-5000 mg Na^+/Kg body weight and a lethal NOEL of 1500 mg Na^+/Kg body weight. At 500 mg Na^+/Kg body weight, edema of the gizzard was common while brainstem vacuolation was observed in some. With at least 1,500 mg Na^+/Kg body weight, clinical symptoms included depression, ataxia, and inability to fly or perch. Symptoms in birds that survived for 6 hours usually went away. However, for those who did not survive, death ensued within 45 minutes. Mimicked drought conditions exacerbated the effects. Famine conditions also made the impacts more severe and exhibit more quickly. The study determined that homeostasis fails as low as 266 mg Na^+/Kg body weight (Mineau and Brownlee, 2005). Therefore, to protect the sparrow from reduced coordination and weakness, this was deemed the minimum effect level. The critical toxicological value (CTV) is the concentration above which certain effects are expected. This value may also be considered in terms of quantity of various sized salt crystals to grasp the relative risk of salt that has not yet dissolved into a brine solution (Table 3) (Mineau and Brownlee, 2005).

In summary, the most sensitive terrestrial species to salt are birds through the consumption of salt crystals. Other wildlife species are affected by drinking water with concentrations of chloride greater than 600 mg/L. Damage to vegetation can also have an impact on wildlife habitat by destroying food resources, shelter and breeding and nesting sites.

Table 3 Sodium CTV and number of salt particles for impacts

CTV (mg Na^+/Kg body weight	Effect	Number of worn salt particles	
		0.5 mm diameter particles	2.4 mm diameter particles
266	Homeostasis failure	52	0.47
500	Edema of gizzard	98	0.88
1500	Overt signs of toxicity. Mortality LOEL	294	2.6
3000	LD50	587	5.2

(Mineau and Brownlee, 2005)

4.2 Aquatic life

Aquatic species of concern include fish, macroinvertebrates, insects and amphibians. Ecological risk for various species is assessed by comparing toxicity endpoints and estimated environmental concentrations (EECs). The ratio of the EEC to the most sensitive toxicity endpoint is the Risk Quotient (RQ). This comparison acts as a screening tool, which, if failed, could either lead to a more refined risk assessment or risk management.

Aquatic organisms require chloride to maintain normal physiological functions but only at relatively steady concentrations to which the organism has adapted. Aquatic organisms exposed to excess or widely fluctuating chloride are vulnerable to survival, growth, and/or reproduction risks.

Salt tolerance of the plethora of aquatic species varies tremendously. Depending on whether fish are fresh or salt water species, fish have been reported to tolerate between 400 and 30,000 mg/l. Accordingly, with road salting, salinity increases leading to the growth in abundance of salt tolerant species. Interestingly, aquatic species may adapt to increased levels of chloride with time, such that surviving organisms may develop the means by which to handle the osmotic shock imposed by the excess chloride. Furthermore, saltwater species are not vulnerable to anthropogenic sources of NaCl, except for fluctuations of greater than 10%.

Table 4 presents the toxicity thresholds for NaCl and chloride for various species. These thresholds do not depend on water hardness, alkalinity, or pH. Freshwater aquatic species react differently to various exposures, with effects ranging from acute and lethal to chronic and subclinical. Chronic exposure of cladoceran to chloride at concentrations greater than 730 mg Cl^-/L can interfere with reproduction. Invertebrate species are generally more sensitive to chloride than are vertebrate species. However, the most sensitive species is the fathead minnow, which is impacted at acute levels of 874 mg Cl^-/L, equivalent to 1440 mg NaCl/L, and chronic exposures of 252 mg Cl^-/L, equivalent to 415 mg NaCl/L. Although this species is not native to NH, it has been observed in the state.

Table 4 NaCl and chloride toxicity thresholds for aquatic organisms

Species	NaCl (mg/L)	Cl (mg/L)	Response type	Response
American eel	17,964 – 21,571	10,900 – 13,085	4-day LC50	Acute Survival
Bluegill	14,100	8553	1 day LC50	Acute Survival
	9627 – 12,964	5840 – 7864	4 day LC50	Acute Survival
	20,000	12,132	6 hour LC47	Acute Survival
Brook trout	50,000	30,330	15 minute LC50	Acute Survival
Caddisfly	5526 - 7014	4039 – 4255	4 day LC50	Acute Survival
Chironomid	9995	6063	12 hour LC50	Acute Survival
	5192 – 6637	3795 – 4026	4 day LC50	Acute Survival
Cladoceron	2724 – 7754	1652 – 4704	1 day LC50	Acute Survival
	2308 – 6709	1400 – 4071	4 day LC50	Acute Survival
	2077 – 6031	1261 – 3660	7 to 10 day LC50	Sub-chronic Survival
	1225 – 5777	735 – 3506	7 to 10 day EC50	Sub-chronic reproductive
	4310	2616	7 to 10 day EC50	Sub-chronic weight
	518	314	21 day NOEC	Chronic
	727	441	21 day LOEC	Chronic
Daphnids	2333[1]	1400	4 day LD50	Acute Survival
Diatom	2430	1474	7 to 10 day EC50	Sub-chronic cell numbers
Fathead minnow early life stage	7650 – 10,831	4600 – 6750	4 day LC50	Acute Survival
	2133[1]	1280	7 day LOEL	Sub-chronic

Species	NaCl (mg/L)	Cl (mg/L)	Response type	Response
	415[1]	252	33 day NOEC	Chronic
	580[1]-722[1]	352-433	33 day LOEC	Chronic
Fathead minnow embryos	1440	874	7 to 10 day LC50	Sub-chronic Survival
Fathead minnow larvae	4990	3029	7 to 10 day EC50	Sub-chronic Growth
	5490	3330	7 to 10 day LC50	Sub-chronic Survival
Frog	2540	1524	7 to 10 day LC50	Sub-chronic Survival
Goldfish	7341	4453	4 day LC50	Acute Survival
Indian carp fry	7500	4550	1 day LC50	Acute Survival
	4980	3021	4 day LC50	Acute Survival
Isopod	4896	2970	4 day LC50	Acute Survival
Mosquito fish	10,254 - 17,500	6222 - 10,616	4 day LC50	Acute Survival
Rainbow trout	11,112	6743	4 day LC50	Acute Survival
	20,000	12,312	6 hour LC40	Acute Survival
Rainbow trout egg embryo	2400	1456	7 to 10 day LC50	Sub-chronic Survival
Rainbow trout embryo/Alvin	2630	1595	7 to 10 day LC50	Sub-chronic Survival
Snail	4088	2480	4 day LC50	Acute Survival
Tubificid worm	2007[1]	1204	4 day LC50	Acute Survival

(EC, 2001; USEPA, 1988; Nagpal *et al*., 2003);
[1]Organism toxicity reported only in concentration of Cl; concentration of NaCl calculated from Na:Cl ratio.

The 1988 EPA Chloride Guidance set the Final Acute Value for chloride as 1720 mg/L. EPA has set an acute criterion of 860 mg Cl^-/L by applying a safety factor of 2 to this value. Based on the mean acute values, this criterion does not protect certain organisms, such as some Daphnia (USEPA, 1988). The final chronic value of 230 mg/L was derived by dividing the Final Acute Value by the acute to chronic ratio of 7.593. The acute and chronic criteria are the maximum one-hour average and the maximum four-day average, respectively. Likewise, Minnesota has set the same chronic and acute standards (SCWMC and MPCA, 2006; MPCA, 2000). These chloride criteria only apply when the chloride is associated with sodium. Chloride toxicity increases when it is associated with other cations, such as potassium or magnesium, which may occur once the ions of road salt have dissolved and migrated at potentially different rates.

Cyanide in the anti-caking agents interferes with a fish's breathing mechanism, thereby being lethal. In Minnesota, run-off from the salt piles was reported to contain between 5 and 40 times the amount of free cyanide that is toxic to half of the fish exposed. That which is sprayed on roads is diluted and thus is not a primary source of the problem; rather, it is the concentrated runoff from improperly managed salt piles (MPCA, 2000).

Another mode by which NaCl may impact aquatic organisms is via an increased mobilization of other contaminants, i.e., metals, nutrients and organic contaminants, through runoff mechanisms. Furthermore, the shift in acid buffering capacity may compromise the aquatic ecological integrity.

Water chemistry, including dissolved oxygen, temperature, and other contaminant concentrations, affect the chloride's impact. Conversely, the presence of chloride increases the toxicity of some contaminants and decreases that of others. Nonetheless, based solely on the chloride's toxicity alone, the acute (1-hour average) and chronic (4-day average) guidelines are 860 and 230 mg Cl^-/L, respectively, equivalent to 1433 and 383 mg NaCl/L, respectively. This water quality standard should be protective of all aquatic species in NH.

4.3 Vegetation

Terrestrial, emergent aquatic, and submerged aquatic plant impacts have been correlated with NaCl exposure so much so that NaCl is a registered herbicide. During the 1950s, approximately 14,000 trees along 3700 miles of salt-treated highways died. The NH Highway Department removed these trees and the State initiated over the next two decades investigations into the impacts of road salt on vegetation. Similarly, other states using salt as deicers researched the impacts.

Elevated levels of NaCl in soils generate an osmotic imbalance in plants, which can inhibit a plant's water absorption and stunt root growth. The salt can also interfere with the uptake of plant nutrients and inhibit the plant's long-term growth. NaCl inhibits flowering, seed germination, and growth of roots and stems. Most vegetation damage occurs within 60 feet of the road and is greatest close to the pavement. Nonetheless, impacts have been observed up to 200 meters from treated roads as the contaminated water migrates (Wegner and Yaggi, 2001). Two mechanisms are primarily responsible for the impacts. First, increased salt concentrations in soil and pore water cause salt to be absorbed through the vegetative roots. Second, splash and spray from traffic and wind can deposit salt particles on vegetation (TRD, 1991). Too many particles can damage roots and inhibit growth.

One factor that affects splash and spray accumulation is the surface area of the vegetation, with broad trees and shrubs being more vulnerable. Greater mass of salt applied, increased traffic volume, and closer proximity of the roadway to the vegetation all increase the potential for impacts. Slope of the roadside also influences where salt impacts are exhibited.

Physical symptoms include leaf scorch, late summer coloration, early fall defoliation, reduced shoot growth, and dying twigs and branches in the crown, and in extreme cases, death. Thresholds for sodium and chloride vary by species and other factors including temperature, light, humidity, wind, soil texture and drainage, precipitation, plant size, salt exposure, species tolerance, and water availability. Chloride causes osmotic stress in plant tissues when it is adsorbed and accumulated in the plant. The result is dehydration exhibited by leaf scorch (EC, 2001; TRD, 1991).

The accumulated salinity in soil allows for less moisture retention as well as retardation of water uptake by plants, both of which compromise plant growth and soil erosion control. While precipitation may alleviate the resulting dehydration, in addition to flushing salt deposits from foliage and diluting salt concentrations in soil water, it also causes surface runoff of salt to roadsides, groundwater and surface water (EC, 2001; TRD, 1991; Mineau and Brownlee, 2005).

A rise in temperature increases the rate in uptake of water containing NaCl. Increases in temperature, light, and wind all compound the dehydration impacts of NaCl on plants by increasing evapotranspiration through foliage (EC, 2001; TRD, 1991). Conversely, an increase in humidity decreases evapotranspiration, thereby alleviating salt stress.

Aquatic vegetation is similarly vulnerable to the osmotic pressures. One algal species has demonstrated extreme sensitivity to exposures to chloride; as little as 71 mg Cl^-/L inhibits growth and chlorophyll production, while others can tolerate chloride concentrations between 886 mg/L and 36,400 mg/L. An increase in chloride may also shift the native algal populations towards more nuisance populations. Other aquatic plants exhibit various sensitivities, with growth inhibition observed in desmids at 200 mg Cl^-/L , EC50 equal to 1482 mg Cl-/L in diatoms, and reduced growth and reproduction at 1820 mg Cl-/L in angiosperm (USEPA, 1988). Although noteworthy, the sensitivities exhibited by the algae and desmids do not weigh into the final threshold determination because the toxicity tests were not conducted with measured concentrations of chloride, a biologically significant endpoint, and an aquatic plant of consequence in NH waters.

Terrestrial and aquatic plant species are vulnerable to varying degrees of sodium and chloride. Cellular dehydration is primarily responsible for the toxic effects. Symptoms range from inhibited growth, leaf scorch, and even death. Besides the one species of alga, desmids are the most sensitive aquatic species, impacted at 200 mg Cl^-/L. Table 5 summarizes the toxicity thresholds for various types of vegetation.

Table 5 Toxicity thresholds of vegetation

Pathway	Plant type	Form	Threshold	Units	Response type
Soil	Woody	Na^+	67.5 – 300	Mg/Kg soil	EC25
		Cl^-	215 – 500		EC25
		NaCl	600-1500		EC25
	Herbaceous	Na^+	202 – 270		
Root uptake	All species	Na^+	67..5 – 300	Mg/Kg plant	EC25
		Cl^-	215 – 1500		EC25, LOEL
		NaCl	280 – 66,600		EC25, CTV, NOEL, LOEL
Solution	Wetland	Cl^-	300 – 1500	Mg/L solution	LOEL
		NaCl	280 – 66,600		NOEL, LOEL
	Woody	NaCl	836 – 25,000		EC25, CTV
	Herbaceous	NaCl	<2500 – 10,000		EC25
Surface Water	Algae	Cl^-	71 – 36,400		Inhibition of growth and/or chlorophyll
	Desmid	Cl^-	200-250		Growth inhibition
	Diatom	Cl^-	642		EC50
	Eurasian milfoil	Cl^-	3617 – 4964		50% reduction in dry weight
	Angiosperm (seeds, 9-week old plants, and 13-week old plants)	Cl^-	1820		Reduced germination, dry weight, and shoots

(EC, 2001)

5.0 Conclusions

NH winters demand an effective and affordable means of de-icing roadways. NaCl road salt satisfies these conditions. However, such an agent must also be relatively benign to human and ecological receptors, which requires that the application and management of NaCl be prudent and cognizant of its fate and transport and potential sodium and chloride toxicity. The dissociated ions may migrate directly to surface water or infiltrate to the subsurface environment, ultimately reaching groundwater. Not only does the sodium cation pose risk of hypertension to humans and lethal and sublethal effects on wildlife receptors, it may also disrupt the natural cation balance in soil, thereby tipping the buffering system of the receiving surface waters.

Sodium concentrations in drinking water have increased due to road salt applications. While levels exceeding 20 mg/L threaten salt-sensitive people, others can handle greater concentrations up to 125 mg/L without clinical symptoms. Chloride in drinking water causes organoleptic but not health issues at levels greater than 250 mg/L.

Wildlife is more vulnerable to road salt in that receptors are exposed not only to dissolved salt in drinking water and snow melt but also to salt particles on the roadways and accumulated salt spray on vegetation. Birds, in particular, suffer behavioral impacts including depression and ataxia. These symptoms are due to the renal inability to handle the excess sodium. Mammals are more capable of balancing the burden.

Not surprising considering it is also an herbicide, vegetation is vulnerable to NaCl. The salt from spray and migrated water impairs the vegetation via desiccation and osmotic processes. Unfortunately, without an intact vegetative buffer, downgradient surface water and groundwater are more vulnerable to other contaminants.

The purpose of this report is to identify appropriate standards for road salt impacts for water quality studies. Therefore, the report recommendations will be limited to exposure to NaCl in solution. Other exposure pathways exist, notably birds eating salt crystals and vegetation exposure to soil, but are not germane studies of NaCl in surface and ground waters.

In the following table, the water quality standards needed to protect the most sensitive populations of humans, wildlife, aquatic species and vegetation have been compiled. Standards for sodium, chloride and NaCl are proposed. Generally, it is the sodium cation that poses the primary risk to human and wildlife health; the chloride anion poses the primary risk to aquatic organisms; and vegetation is vulnerable to both ions. For chloride, the information in Table 6 shows that the DES chronic standard of 230 mg/L will be protective of humans, wildlife, aquatic organisms and most vegetation. However, to be protective of more sensitive aquatic plant species, this threshold should be more stringently set at 200 mg/L. For sodium, a threshold of 20 mg/L should apply to drinking water sources, but not to surface waters in general.

Table 6 Summary of NaCl, Sodium and Chloride Guidelines

	Na^+ (mg/L)	Cl^- (mg/L)	NaCl (mg/L)	Comments
Human health	20	250		EPA drinking water quality standards
Wildlife		600	1000	Nagpal et al (2003)
Aquatic organisms		860 – 1-hour average 230 – 4-day average		DES water quality standard
Terrestrial and emergent plants		300	800	Groundwater source
Aquatic plants		200 – 36,400		USEPA, 1988

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