Stormwater
The Journal for Surface Water Quality Professionals

Environmental Impacts of Road Salt and Alternatives in the New York City Watershed

In our May/June 2001 issue, Janis Keating looked at what cities around the country are doing about deicing roads. This article takes a close look at salt's potential impacts, with special focus on a single watershed.

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The use of road salt as a deicer on roads and other impervious surfaces is the preferred method to promote safe motor vehicle and pedestrian travel during winter months. The most commonly used deicing salt is sodium chloride (NaCl), which is readily available and inexpensive and effectively depresses the freezing point of water to melt ice. But what are the impacts of road-salt application to drinking-water supplies and watershed ecosystems?

Historically, regulators in the management of nonpoint-source pollution have been concerned principally with heavy metals, nutrients, hydrocarbons, pathogens, and sediment that scour from road surfaces in stormwater runoff and contaminate groundwater and surface-water supplies. Recently, after more than half a century of its widespread use in North America, the application of NaCl and its environmental consequences have come under scrutiny by the environmental and scientific communities as well as regulators and legislators. Growing concern over roadside habitat degradation, wildlife kills, and water-quality issues in Canada prompted Environment Canada (EC) to conduct a comprehensive assessment of road-salt application to determine whether conventional deicers should be considered toxic substances under the Canadian Environmental Protection Act (EC, 1999). California and Nevada restrict road-salt use in certain areas to reduce chloride injury to roadside trees. Massachusetts turned to alternative road deicers to prevent sodium contamination of residential drinking wells. New York State legislators recently proposed a pilot study in the New York City watershed to examine road-salt alternatives that might be more protective of drinking-water quality.

Road salt is often applied in areas with narrow buffers to surface waters.

There are compelling concerns behind these legislative decisions. According to the National Research Council (NRC), road-salt use in the United States ranges from 8 million to 12 million tons of NaCl per year. Massachusetts, New Hampshire, and New York report the highest annual road-salt loadings, with Massachusetts the highest at 19.94 tons/lane-mi./yr. New York's annual road-salt loading averages 500,000 tons/yr. or 16.6 tons/lane-mi./yr. (NRC, 1991). The New York State Department of Transportation (NYSDOT) requires a road-salt application rate of 225 lb./lane-mi. for light snow and 270 lb./lane-mi. for each application during rapidly accumulating snow (NYSDOT, 1993). What has been the fate of millions of tons of NaCl that has been deposited on impervious surfaces in close proximity to unfiltered drinking-water supplies? This article reviews the findings of several government and peer-reviewed road-salt studies and discusses them in the context of environmental and water-quality impacts in the New York City watershed.

New York City's Watershed

Nineteen reservoirs and three controlled lakes in upstate New York provide more than 9 million consumers with 1.5 billion gal. of unfiltered drinking water daily. The reservoirs and lakes are located in three distinct watersheds–Croton, Catskill, and Delaware–covering 2,000 $mi.^2$ of forested, agricultural, and suburban lands. There are approximately 6,000 mi. of paved roadways in the watersheds, where road-salt application ranges from 37 to 298 tons/lane-mi./yr. Two-lane town, county, and state roads receive 37 tons/lane-mi./yr. The Taconic Parkway, which travels through three watershed sub-basins in the Croton watershed, receives 75 tons/lane-mi./yr. Interstate 84 travels through two sub-basins in the Croton watershed and receives 298 tons/lane-mi./yr. (Heisig, 2000).

The 1997 New York City Watershed Memorandum of Agreement regulates land use and water-quality protection in the New York City watersheds. A comprehensive protection scheme signed by more than 60 watershed towns, New York City, New York State, USEPA, and five environmental organizations, the Watershed Agreement protects drinking water through land acquisition, land-use regulations, and partnership programs. Most of the regulations and partnership programs are framed to prevent pollutants from entering the water supply. Road salt, however, is a pollutant that received little attention in the Watershed Agreement. Aside from a partnership program in which New York City pays to construct salt and sand storage facilities in watershed towns, road salt is not specifically regulated in the Watershed Agreement.

Environmental Fate and Transport

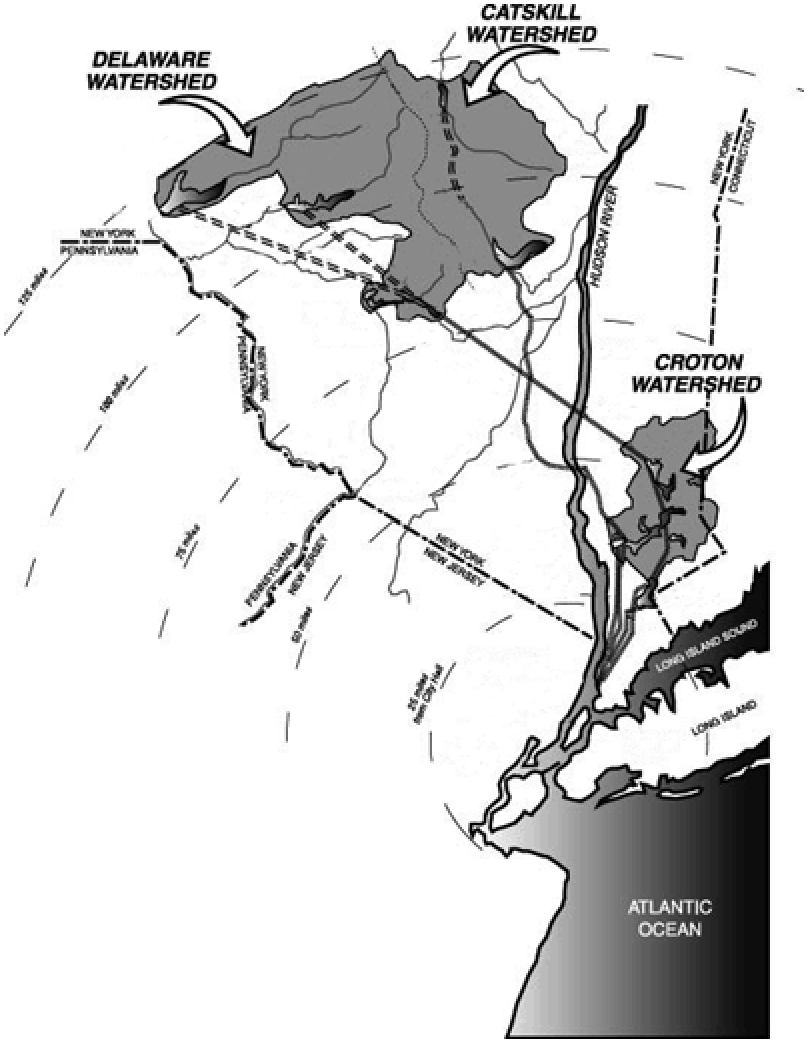
Chloride salts are composed of approximately 60% chloride and 40% positive ion. Deicing operations use calcium, potassium, and magnesium chlorides, but to a lesser degree than NaCl. These salts may be applied in liquid or crystalline form, either of which can be used in conjunction with abrasives. Liquid salt solutions provide immediate deicing upon application to roads and sidewalks. Crystalline forms are slower and longer acting than liquid solutions. Sodium ferrocyanide is added to chloride salts to prevent clumping during storage and application. In water, sodium ferrocyanide can be photolyzed to release approximately 25% cyanide ions (EPA, 1971).

Runoff to surface waters and percolation to groundwater are the most common mechanisms for road salts to enter water supplies. Infiltration is more common for groundwater-based supplies. In the New York City watersheds, groundwater is a major contributor to streams. Groundwater discharge accounts for at least 60% of total annual stream flow in the Croton watershed. Chloride concentration in groundwater supplies exhibits a relatively linear relation to road-salt application rate or two-lane road density throughout the year. In surface-water supplies, chloride concentration depends on salting intensity, soil type, climate, topography, and water volume, with larger water bodies exhibiting lower concentrations through the process of dilution. Deicing salts applied to roads during winter are the primary source of solutes to groundwater in the Croton watershed, where chloride concentrations in baseflow of sampled streams ranged from 18 to 280 mg/l (Heisig, 2000).

NaCl dissociates in aquatic systems into chloride ions (CL^-) and sodium cations (Na^+). While sodium may bond to negatively charged soil particles or be taken up in biological processes, chloride ions are less reactive and can be transported to surface waters through soil and groundwater. Road salts applied to roadways can enter air, soil, groundwater, and surface water from direct or snowmelt runoff, release from surface soils, and/or wind-borne spray. These salts remain in solution in surface waters and are not subject to any significant natural removal mechanisms (EC, 2000). Their accumulation and persistence in watersheds pose risks to aquatic ecosystems and to water quality. Approximately 55% of road-salt chlorides are transported in surface runoff with the remaining 45% infiltrating through soils and into groundwater aquifers (Church and Friesz, 1993). Chloride ion exchange in soils is predicted to reach a steady-state concentration–the point at which input at the subsurface equals output in baseflow–of 400 mg/l within 200 years of initial salt application (Howard et al., 1993).

Soils

Soil biotic communities cycle nutrients, decompose organic matter, and increase soil aeration and water-holding capacity. EC (2000) reported soil chloride concentrations exceeding 200 mg/l as far as 200 m from roadsides. EPA has set the Secondary Maximum Contaminant Level (SMCL) for chloride at 250 mg/l in drinking-water supplies.



Exposure to NaCl inhibits some soil bacteria at concentrations as low as 90 mg/l, which ultimately compromises soil structure and thereby inhibits erosion control. Federal standards for turbidity require that a drinking-water supply not exceed 5 nephelometric turbidity units; however, the creation of friable soils from bacteria die-off can increase the suspension of sediment in runoff and contaminate drinking-water supplies to levels that exceed standards. These changes in soil conditions could lead to turbidity violations and trigger an automatic filtration order requiring New York City to construct a filtration plant at the cost of up to $8 billion.

Vegetation

Elevated sodium and chloride levels in soils create osmotic imbalances in plants, which inhibit water absorption and reduce root growth. Salt also disrupts the uptake of plant nutrients and inhibits long-term growth. EC (2000) cites numerous studies attributing tree injury and decline to road-salt application, concluding that NaCl can cause severe injury to the flowering, seed germination, roots, and stems of roadside plant species. Damage to vegetation can occur up to 200 m from roadways that are treated with deicing salts. Up to 50.8% of woody plant species are sensitive to NaCl, and many of these have disappeared from Canadian roadsides. Of the 15 principal tree genera occurring in Canadian forests, 11 have been rated as sensitive to road salt. Threshold values for woody and herbaceous plant forms can be as low as 67.5 ppm in soils, with pine seedlings being the most sensitive; 280 ppm in herbaceous tissues; and 200 ppm in woody tissues. Plants may be sensitive to concentrations of either or both salt ions present in soil. An Ontario study reported a soil chloride concentration of 1,050 ppm in soil taken from a highway median and 890 ppm in soil sampled 10 m from the highway (Hofstra and Smith, 1984). NaCl exposure as low as 100 ppm in soil inhibits seed germination and root growth rates for grasses and wildflowers. As a result of salt concentrations in roadside soils, salt-tolerant halophytic plant species, formerly endemic to coastal wetlands, now colonize inland roadsides (EC, 2000). These species include cattails and *Phragmites*, both of which can be indicators of degraded wetlands subject to excessive nutrient loading and/or salt contamination.


PHOTO: RIVERKEEPER

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Road salt eventually finds its way into Kensico Reservoir, one of New York' s drinking-water sources.

Damage to vegetation can amplify adverse impacts on drinking-water quality in the New York City watersheds. Degradation of soils and vegetation in buffer areas between roads and watercourses compromises the retention and processing of pollutants transported in stormwater runoff and diminishes the beneficial value of buffer zones to groundwater sources and reservoirs. Impacts to water quality can be particularly acute when high level-of-service roads are adjacent to drinking-water reservoirs insulated by narrow buffers, as is the case in several of the New York City watershed sub-basins.

Wildlife

Damage to vegetation degrades wildlife habitat by destroying food resources, habitat corridors, shelter, and breeding or nesting sites. Behavioral and toxicological impacts to wildlife also are associated with road salts. Sodium-deficient wildlife sometimes travel great distances to ingest road salt. Many animals tend to overshoot their salt deficit and then drink salty snow melt to relieve thirst, which increases salt toxicity in blood and tissues (EC, 2000). While wildlife impacts might not be construed as directly relating to water-quality impacts, kills and population declines among salt-sensitive species can be indicators of salt toxicity in aquatic ecosystems.

Mammals. In Jasper National Park, AB, road-salt ingestion is responsible for kills of elk and bighorn sheep. In northern Ontario and Quebec, ingestion of salty snowmelt is a major cause of moose/vehicle accidents. Salt toxicosis has not been documented in moose or deer, but moose drinking salty water lose their fear of vehicles and humans. Road-salt—related mortality of small mammals commonly killed by traffic, while probably significant, remains to be studied. The LD_{50} (lethal oral dose at which 50% of a population dies) for rats is 3,000 mg/kg body mass (EC, 2000), which is comparable to the lethal mean for birds.

Birds. EC (2000) cites 12 reports of bird kills associated with road salt in the US, Canada, and Germany. Two reports involved kills in excess of 1,000 birds. Seed-eating birds may not be able to distinguish between road-salt crystals and the mineral grit their diets require. Laboratory studies of sparrows consuming salt particles at the upper limits of their known preference range reveal that ingestion of 0.25 NaCl particles (266 mg/kg) results in a breach of homeostasis; ingestion of 1.4 particles (1,500 mg/kg) may result in death (median lethal dose = 2.8 at 3,000 mg/kg). This means behavioral abnormalities can occur in small bird species with ingestion of a single salt particle and death can occur with ingestion of two particles. Salt toxicosis in birds increases their vulnerability to car strike. The local human inhabitants near Mount Revelstoke Park, BC, refer to winter finches as "grille birds" because of the large numbers that collect on the grilles of moving vehicles. Although there is a high correlation between the distribution of winter finches and the Canadian road system receiving salt, risk characterization is difficult to assess in terms of kill frequency because of the various mechanisms–fatal attraction, toxicosis-induced car strike, lethal ingestion–that contribute to mortality. Nevertheless, EC concluded that transportation officials probably underestimated the contribution of road salt to wildlife kills.

Aquatic Biota. Road-salt loadings in surface waters vary with regional climate conditions, season, and air temperature fluctuation. Snowmelt may proceed gradually overall, but it increases dramatically following application of road salt. Shock loads of salt to aquatic ecosystems might last less than a day following application, with concentration decreasing thereafter. Salt held in solution in snow or deposited on surface soil layers is readily dissolved by rain and can be transported to receiving waters in runoff. Prolonged retention of salt in streambeds or lakebeds decreases dissolved oxygen and can increase nutrient loading, which in turn promotes eutrophication.

Toxicity responses of aquatic organisms to NaCl vary. Laboratory studies report that the LC_{50} for six freshwater fish and crustacean species exposed to NaCl for one day ranged from 2,724 to 14,100 mg/l with a mean of 7,115 mg/l (Cowgill et al., 1990). These values decreased significantly as exposure time increased. The LC_{50} for 17 species of fish, amphibians, and crustaceans exposed to NaCl for seven days ranged from 1,440 to 6,031 mg/l with a mean of 3,345 mg/l (EC, 2000).

Reports of chloride concentrations in highway runoff run as high as 19,135 mg/l. Salt tolerance of fishes ranges from 400 to 30,000 mg/l, greater than the salt concentration of seawater. A seven-day exposure of 1,000 mg/l is lethal to rainbow trout (NRC, 1991). While an estimated 10% of aquatic species will exceed their critical tolerance values for chloride with prolonged exposure to concentrations above 220 mg/l, many of the macroinvertebrates upon which the more tolerant species feed might exhibit lower tolerances. Stream studies in northern New York revealed that benthic diversity decreases as salinity increases and dominance of salt-tolerant invertebrates is synchronous with periods of road-salt application. Salinity stresses the periphyton community upon which benthic grazers forage and inhibits microbial processing of leaf litter (EC, 2000). Reduction of primary productivity causes repercussions at the top of the food chain in addition to the stress salinity imposes on the organisms themselves. The presence of salt in aquatic ecosystems also releases toxic metals from sediment into the water column and impairs distribution and cycling of oxygen and nutrients.

Human Health Impacts


PHOTO: RIVERKEEPER

New York State Department of Transportation plowing and spreading.

A Federal Highway Administration (FHWA) study concluded that the major objection to concentrations of sodium in public water supplies arises from the taste preference of consumers (Winters et al., 1985). EC agreed that the primary problem of road salt in drinking water is its adverse effect on taste. NRC’s Transportation Research Board reported a more serious concern of road salt’s impact on human health. Excess dietary sodium is associated with hypertension, and up to 30% of the US population could have borderline to pronounced hypertension. This amounts to nearly 3 million New Yorkers potentially affected by road-salt loading. EPA requires that sodium concentrations in drinking water not exceed 20 mg/l and requires monitoring and reporting of higher levels in public water supplies (NRC, 1991).

Infrastructure Impacts

In addition to the public health and environmental problems associated with chloride deicers, the corrosivity of road salt adversely impacts motor vehicles and infrastructure. Chloride ions in salt increase the conductivity of water, which induces and accelerates corrosion. In automobiles, corrosion can affect critical vehicle parts, such as brake linings, frames, and bumpers, and can cause cosmetic corrosion. Corrosion protection practices increase the cost of auto manufacturing by nearly $4 billion/yr. (NRC, 1991).

Although road salt rarely jeopardizes the structural integrity of bridges, its corrosivity damages bridge decks. Chloride ions penetrate concrete and corrode reinforcing rods, causing the surrounding concrete to crack and fragment. Installing corrosion protection measures in new bridges and repairing old bridges could cost Snowbelt states between $250 million and $650 million per year. Similarly, road salt causes reinforcing steel in parking garages to rust, thereby compromising the structural integrity of the surrounding concrete. Installing corrosion protection measures in parking garages and restoring damaged parking garages could easily cost Northeast and Midwest states between $75 million and $175 million per year. Other roadside hardware and some nonhighway objects near salt-treated roads also are affected by the corrosive properties of road salts (NRC, 1991).

Road-Salt Alternatives

Calcium Magnesium Acetate

NRC (1991) examined calcium magnesium acetate (CMA) as an alternative to road salt in deicing operations. CMA solution is prepared by dissolving solid CMA in water. Optimal concentration in solution is 25%. NRC concluded that CMA is relatively harmless to plants and animals, noncorrosive to metals, and nondestructive to concrete and other highway materials. Because of its low density and small particle size, CMA may be dusty during handling and storage and may blow off roadways after spreading. When exposed to moisture, CMA can clog spreading equipment.

The calculated ratio of CMA to salt for comparable ice melting is 1.7:1. In practice, however, the amount varies. An Ontario study lowered the ratio to 1.5:1 and found CMA to be effective in penetrating light snowpack and preventing pavement icebond (Manning and Crowder, 1989). A study by Wisconsin Department of Transportation (1987) reported application rates of CMA at 1.2-1.6 times greater than salt. CMA also functions as an effective anti-icer when applied prior to or at the outset of snow events at rates 20-40% higher than salt.

Washington State uses CMA in anti-icing operations to reduce the volume of sand-based abrasives that enter salmon spawning streams in snowmelt and stormwater runoff (Washington State Department of Transportation, personal communication).

CMA acts more slowly and is less effective than salt in cold conditions. Notwithstanding the difference in application rate, CMA's deicing performance is comparable to that of salt but less successful in melting accumulated snow and ice. The California Department of Transportation (1989) found CMA effective in preventing the formation of snowpack but less effective than salt treatments in removing heavy snowpack and less effective at temperatures below 23ºF. In general, nearly all studies of CMA rated the substance as an acceptable deicer but not as effective or consistent as salt when applied in equal amounts. As experience with CMA increases, some highway agencies predict its ratio to salt application will approach 1:1.

Health and Environmental Impacts. Comprehensive studies performed by Caltrans (Winters et al., 1985) and the National Cooperative Highway Research Program (NCHRP) found CMA to be much more environmentally benign than NaCl (Horner et al., 1988). The Caltrans study found few adverse impacts associated with CMA. CMA was less toxic to fish than road salt, although Caltrans associated CMA concentrations of 5,000 mg/l with slightly delayed hatching in rainbow trout. At high exposure levels CMA is more toxic to phytoplankton than sodium chloride. Inhibitory effects in algae occurred at CMA concentrations of 85 mg/l; algae did not exhibit any inhibition from sodium chloride at test concentrations. The CMA LC_{50} for rainbow trout is 18,700 versus the NaCl LC_{50} of 12,200 (Cheng and Guthrie, 1998).

In soils, CMA tends to exchange calcium and magnesium with other metals already present. CMA can extract iron, aluminum, sodium, and potassium from roadside soils but is less harmful to plants than road salt. Of 18 tree species tested, only the Russian olive was more sensitive to CMA than to NaCl (NRC, 1991). CMA may actually stimulate plant growth by improving soil structure and permeability (Cheng and Guthrie, 1998).

NCHRP reported that CMA decomposes within two weeks when in soils at temperatures above 50ºF. At 35.6ºF, decomposition time was around four weeks. Two potential problems associated with CMA are temporary oxygen depletion in water from CMA decomposition and the potential for phosphorous enrichment of surface waters that are exposed to high concentrations of CMA derived from agricultural products.

Costs. The average cost of road salt is $30/ton. NRC (1991) estimated the cost of CMA between $500 and $700/ton. The $500 figure represents use of a corn fermentation process to derive acetic acid, which reacts with dolomitic lime to produce CMA. Chevron Chemical Company produces CMA using acetic acid from natural gas and sells the product for $600-$700/ton delivered. Conversion to CMA would incur additional costs to municipalities in the modification of storage, handling, equipment and spreading operations.

Potassium Acetate

Potassium acetate (KA) is often used as a base for commercial chloride-free liquid deicer formulations. Its advantages include low corrosion, relatively high performance, and low environmental impact. Although less study information is available on KA, some of the findings are clear.

Health and Environmental Impacts. Health impacts of KA are slight. Inhalation of the substance may cause mild irritation to the respiratory tract. The Material Data Safety Sheet for KA documents no significant adverse effects from skin and eye contact with the product.

As with NaCl and CMA, KA can temporarily deplete oxygen in aquatic ecosystems but may stimulate plant growth. The 96-hour LC_{50} for rainbow trout is 1,500 mg/l. Along with CMA, KA is one of the most benign road-salt alternatives because it contains nonpersistent, biodegradable acids. Cryotech CF7, a commercial form of KA, has been selected for use in Yosemite National Park. KA is stable and is removed from application areas by flushing, dispersion, and dilution. Davis et al. (1994) concluded that KA does not penetrate groundwater aquifers and does not impact water chemistry. Cost of KA is $700-$800/ton.

Conclusions

Applying road salt in deicing operations could create significant adverse health, environmental, and infrastructure problems. Equally troubling is the fact that New York State applies up to 298 tons of road salt/lane-mi./yr. in the unfiltered drinking-water—supply watersheds for more than 9 million citizens. This level of salt use jeopardizes the health of consumers having heart or kidney disease, destroys protective vegetation and soil, and corrodes automobiles, bridges, and other infrastructure.

CMA and KA both appear to be viable road-salt alternatives. No significant health, environmental, or infrastructure impacts occur with the use of these alternatives. CMA is the most studied of all road-salt alternatives; more field studies should be performed using KA. Both products are preferable to road salt in the New York City drinking-water—supply watersheds, which supply drinking water to more than half of New York State’s population.

The biggest drawback to using CMA and KA is high cost. It will be a challenge to mandate or obtain buy-in from watershed communities to use these products at $500-$700/ton versus $30/ton for road salt. Perhaps some communities will recognize the cost savings to public health, the environment, and local infrastructure from using road-salt alternatives. At present, however, the most likely mechanism for introducing CMA and KA in the New York City drinking-water—supply watersheds is through legislative mandate.

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