Appendix G

Annotated Bibliography
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Appendix G: Annotated Bibliography

Note: This bibliography is not intended to be comprehensive or exhaustive but represents a cross section of research related to chloride from road salt and its environmental impacts. The primary indexes searched in completing this literature review were:

- BIOSIS Previews/Biological Abstracts: Indexes over 5000 publications, conference papers, technical reports and chapters of books in the biological and medical literature.
- Environmental Sciences and Pollution Management Database: This database provides comprehensive, multidisciplinary coverage of the environmental sciences. Abstracts and citations are drawn from over 6000 sources including scientific journals, conference proceedings, reports, monographs, books and government publications. Incorporates Pollution Abstracts, Water Resources Abstracts, and other specialized databases. Areas of coverage include agricultural and environmental biotechnology, ecology, energy resources, environmental engineering, environmental impact statements (U.S.), pollution, toxicology & toxic emissions, and water resource issues.
- Web of Science: Interface for the ISI Citation Index products which cover over 8,000 international journals in the sciences, social sciences, and arts and humanities.

Annotations are generally excerpted from index or paper abstracts, and may have been edited for length. Where no annotation is provided, the title or key words suggest the paper is worth review but there was no abstract available and/or the paper was not readily available.

BIOTIC IMPACTS


This study determined lethal dose levels of road salt on selected macroinvertebrates from a Michigan, USA wetland under different testing conditions and related those levels to *in situ* chloride concentrations of standing water habitats along multi-lane highways. We conducted simultaneous acute (24 and 96 h) and chronic (15 d) toxicity experiments using laboratory containers, containers adjacent to a wetland, and *in situ* modular field PVC microcosms. Data showed that *Callibaetis fluctuans*, *Physella integra*, *Hyalella azteca*, and *Chaoborus americanus* had relatively high tolerance to elevated road-salt levels. Depending on test condition, road-salt 96 h LC$_{50}$ estimates ranged from greater than 5000 mg/l (2558 mg/l Cl$^{-}$) to >10,000 mg/l (4502 mg/l Cl$^{-}$) road salt for *C. fluctuans* and *P. integra*, respectively. For *H. azteca* and *C. americanus*, mortality was generally low at all salt concentrations, with road-salt 96 h LC$_{50}$ estimates >10,000 mg/l. Chloride concentrations of 43 impacted Michigan wetlands ranged from 18 to 2700 mg/l Cl$^{-}$, with 75% <334 mg/l, indicating that macroinvertebrate LC$_{50}$ chloride estimates for the study species are well above most concentrations of the 43 wetlands.

To estimate the effect of traffic emissions on the vegetation composition of coniferous forests near to motorways, three transects of 520 m length were studied by analyzing vegetation composition, soil parameters and deposition data in the Munich-area, Southern Germany. The detected patterns suggest that motorways have an impact on the vegetation composition in the neighborhood of roads. Depending on the wind direction, the influences of the motorways reaches up to 230 m on downwind side and up to 80 m on upwind side. The vegetation is mainly affected by the deposition of nitrogen deriving from fuel combustion and by basic substances added to road salt. By monitoring vegetation changes near to motorways, it is possible to estimate the areas where harmful alterations of the ecosystem can be expected. Vegetation near motorways was strongly influenced by traffic-borne nitrogen.


Field and laboratory experiments were conducted to examine the effects of road salt (NaCl) on stream macroinvertebrates. Field studies investigated leaf litter processing rates and functional feeding group composition at locations upstream and downstream from point source salt inputs in two Michigan, USA streams. Laboratory studies determined the effects of increasing NaCl concentrations on aquatic invertebrate drift, behavior, and survival. Field studies revealed that leaves were processed faster at upstream reference sites than at locations downstream from road salt point source inputs. However, it was sediment loading that resulted in partial or complete burial of leaf packs that affected invertebrate activity and confounded normal leaf pack colonization. There were no significant differences that could be attributed to road salt between upstream and downstream locations in the diversity and composition of invertebrate functional feeding groups. Laboratory drift and acute exposure studies demonstrated that drift of Gammarus (Amphipoda) may be affected by NaCl at concentrations greater than 5000 mg/l for a 24-h period. This amphipod and two species of limnephilid caddisflies exhibited a dose response to salt treatments with 96-h LC$_{50}$ values of 7700 and 3526 mg NaCl/l, respectively. Most other invertebrate species and individuals were unaffected by NaCl concentrations up to 10,000 mg/l for 24 and 96 h, respectively.


Sodium chloride (NaCl) is widely used as a deicing agent on roadways. There are numerous anecdotal reports of poisoning of passerine birds by road salt in the United States and Canada, but little is known about the toxicity of NaCl to songbirds. The objectives of this study were to determine the lethal dose range for NaCl in a representative passerine species (house sparrow (*Passer domesticus*)); to determine the clinical, physiologic, and pathologic effects of sublethal and lethal oral NaCl exposure; and to assess the potential for recovery after exposure to granular salt or highly concentrated salt solutions. Results indicated an approximate mean lethal dose (LD$_{50}$) of 3,000-3,500 mg/kg in water-deprived birds, which is similar to mammalian values. These results indicate that passerines ingesting relatively small numbers of road salt granules or small quantities of highly concentrated NaCl solutions are at risk of sodium poisoning.

Development and growth (continuous in fish) are controlled by 'internal factors' including CNS, endocrinological and neuroendocrinological systems. Among vertebrates, they also are highly dependent on environmental conditions. Among other factors, many studies have reported an influence of water salinity on fish development and growth. In most species, egg fertilization and incubation, yolk sac resorption, early embryogenesis, swimbladder inflation, larval growth are dependent on salinity. In larger fish, salinity is also a key factor in controlling growth. Do the changes in growth rate that depend on salinity, result from an action on: (1) standard metabolic rate; (2) food intake; (3) food conversion; and/or (4) hormonal stimulation? Better growth at intermediate salinities (8-20 psu) is very often, but not systematically, correlated to a lower standard metabolic rate. Numerous studies have shown that 20 to > 50% of the total fish energy budget are dedicated to osmoregulation. However, recent ones indicate that the osmotic cost is not as high (roughly 10%) as this. Data are also available in terms of food intake and stimulation of food conversion, which are both dependent on the environmental salinity. Temperature and salinity have complex interactions. Many hormones are known to be active in both osmoregulation and growth regulation, e.g. in the control of food intake. All of these factors are reviewed. As often, multiple causality is likely to be at work and the interactive effects of salinity on physiology and behaviour must also be taken into account.


The deposition of chemical pollutants into roadside wetlands from runoff is a current environmental concern. In northern latitudes, a major pollutant in runoff water is salt (NaCl), used as de-icing agents. In this study, 26 roadside ponds were surveyed for amphibian species richness and chloride concentration. Acute toxicity tests (LC$_{50}$) were performed on five locally common amphibian species using a range of environmentally significant NaCl concentrations. Field surveys indicated that spotted salamanders (*Ambystoma maculatum*) and wood frogs (*Rana sylvatica*) did not occupy high chloride ponds. American toads (*Bufo americanus*) showed no pond preference based on chloride concentration. Acute toxicity tests showed spotted salamanders and wood frogs were most sensitive to chloride, and American toads were the least. Spring peepers (*Pseudacris crucifer*) and green frogs (*Rana clamitans*) showed intermediate sensitivities. We concluded that chloride concentrations in ponds due to application of de-icing salts, influenced community structure by excluding salt intolerant species.


An urban stream was monitored for chlorine, sodium, and calcium ions. Winter peaks of concentration were found to be generally associated with periods of low discharge, although there was little direct correlation between salt levels and discharge. In summer, when water levels fall due to evaporation, high temperatures and low rainfall, the correlation was stronger and fairly high levels of salt were found. Laboratory and field experiments indicated that Gammarus and Hydropsychidae are apparently unaffected by chloride pulses up to 800 mg/l. In one field experiment, a pulse of 2165 mg/l Cl increased the drift of all organisms in a salted channel.

Forty one tons of salt (NaCl) were applied in 72 applications in the winter of 1987-88 to a 2 km study section of Route 28N in the central Adirondack region near Newcomb, New York. Four sample streams feeding into Rich Lake are located along this section of highway. Salt was generally applied with sand in a 7:1 ratio of sand to salt, but occasionally straight salt was applied. There was no significant difference in chloride concentrations measured at 50 m and at 100 m downstream. Chloride levels in all streams and in each stream individually were significantly higher (P<0.01) downstream (50 m and 100m samples combined) than upstream. Chloride was as much as 66 times higher in the downstream samples. The overall mean chloride level upstream was 0.61 mg/l and 5.23 mg/l downstream. A total of 29 families of aquatic insects were identified using artificial substrate samplers. Twenty families were identified from the downstream samples, 24 families from upstream. Chironomidae was the most abundant family identified, making up 83% of upstream and 90% of downstream samples. The results of the study indicate a significant decrease in the diversity of aquatic insects colonizing artificial substrates downstream compared to the upstream portions of all streams studied. No Name Brook was the only stream to have significantly different upstream vs. downstream diversity when analyzed individually. No Name Brook also had the highest mean downstream chloride concentration. Among the streams analyzed, the smaller the flow rate, the higher the downstream chloride concentration and the greater the difference in diversity between upstream and downstream samples. The quotient of similarity between upstream and downstream samples was also inversely related to chloride concentration. The higher the downstream chloride concentration, the less similarity between upstream and downstream samples.


The addition of 1,000 ppm sodium chloride to a small stream in order to simulate road salt loading resulted in a reduction in algal density and an increase in bacterial density during a four week exposure period. The scanning electron microscope was used to identify changes in the spatial pattern of periphyton community structure using specially prepared slate substrates which were placed in the stream at the onset of the study. Phytophagous invertebrates increased algal diversity at the control station by preventing the dominant alga, Cocconeis placentula, from crowding out the other algal colonizers. Algal diversity remained lower at the salt stressed station as did algal density, fungal parasitism and invertebrate herbivory throughout the four week experiment.


The application of road de-icing compounds during the winter has the potential to result in the contamination of nearby freshwater habitats and affect amphibians breeding in those habitats. We conducted a study of the effects of several de-icing and associated compounds (sodium chloride, magnesium chloride, calcium acetate, magnesium acetate, sodium ferrocyanide, and sodium formate) on the tadpoles of three species of anurans:
African clawed frogs (*Xenopus laevis*), American toads (*Bufo americanus*), and green frogs (*Rana clamitans*). The survivorship of *X. laevis* tadpoles was negatively affected by MgCl$_2$, but not by NaCl. The survivorship of *R. clamitans* tadpoles was negatively affected by both NaCl and MgCl$_2$. The tadpoles of *B. americanus* were not affected by the concentrations of NaCl and MgCl$_2$ used in this study. Our results suggest that contamination of freshwater habitats by de-icing and associated compounds could potentially adversely affect at least some anuran populations, but that this potential can vary from species to species, and from compound to compound.


Extensive analysis of various environmental impacts of road salts for the purpose of assessing toxicity and potential management measures.


An extensive review of the Canadian and United States literature conducted as background paper to the Environment Canada 2001 Priority Substances List assessment report. Determined that a relatively small number of studies have been conducted investigating road salt in the aquatic environment. Road salt impacts, defined as increased chloride concentrations, were most pronounced in urban areas and areas located near heavily salted highways. Furthermore, there is some evidence of more gradual increases in chloride concentrations in lakes in these regions, in part a result of road salt application. Fewer studies have investigated the impacts of road salt to aquatic ecosystem structure and function. However, some small, shallow lakes have been shown to become meromictic, benthic drift has increased in some streams with pulses of road salt being flushed through the system, and other alterations in benthic and phytoplankton communities noted. An extensive review was conducted of laboratory studies investigating the toxicity of sodium, calcium, potassium, and magnesium chlorides. By far the largest data sets were obtained for sodium chloride. Magnesium and potassium chloride appear to be more toxic than sodium chloride for all organisms investigated. Plankton and invertebrates appear to be more sensitive to calcium than sodium chloride while the reverse appears to occur for fish. Most laboratory studies were conducted over short time intervals (i.e., 4 days or less) and investigated mortality. Tolerances were high, with LC$_{50}$ ranging from 1,400-13,085 mg/L chloride. However, this range also spans the range of chloride concentrations observed in road salt snow melt, storm sewers, and urban creeks and rivers. Chloride concentrations in this range also have been observed in wetlands near leaking road salt depots. A few studies were conducted over a 7- day period with EC$_{50}$ ranging from 874-3,330 mg/L chloride. Chloride concentrations in this range have been observed in some urban creeks, rivers, and ponds. Chronic toxicity (i.e., exposure to elevated chloride concentrations over extended time periods) was estimated as ranging from 150-1,402 mg/L chloride. Concentrations in this range have been observed for salt- impacted creeks, rivers, ponds, and lakes, again primarily in urban areas or areas near major highways.


The quality of aquatic habitat in a stormwater management facility located in Toronto, Ontario, was assessed by examining ecotoxicological responses of benthic invertebrates exposed to sediment and water from this system. Besides residential stormwater, the
facility receives highway runoff contaminated with trace metals, polycyclic aromatic hydrocarbons (PAHs), and road salt. The combined flow passes through two extended detention ponds (in series) and a vegetated outlet channel. Toxicity of surficial sediment collected from 14 longitudinally arrayed locations was assessed based on 10 acute and chronic endpoints from laboratory tests with four benthic organisms. Greatest overall toxicity was observed in sediment from sites in the upstream pond, where mortality to amphipods and mayflies reached up to 100%. Downstream pond sediment was less toxic on average than the upstream pond sediment, but not the outlet channel sediment where untreated stormwater discharges provided additional sources of contamination. Macroinvertebrate communities in sediment cores were depauperate and dominated by oligochaetes and chironomids, with minimum densities and diversity at the deeper central pond sites. While sediment toxicity was associated with high concentrations of trace metals and high-molecular weight PAHs, benthic community impoverishment appeared related to high water column salinity.


Germination and growth of wetland plant seeds were studied after application of roadside snowmelt at concentrations of 100% and 20%, using tap water as a control. Only two species, *Typha latifolia* and *Lythrum salicaria*, germinated in plants watered with 100% roadside snowmelt. Germination in seeds watered with 20% snowmelt was 2-19.2%, depending on variety, compared with 5.8-30% with the control water. After one month of growth, community biomass, species diversity, evenness and richness all decreased significantly with increasing snowmelt concentration.


Deicing agents, primarily road salt, are applied to roads in 26 states in the United States and in a number of European countries, yet the scale of impacts of road salt on aquatic organisms remains largely under-studied. The issue is germane to amphibian conservation because both adult and larval amphibians are known to be particularly sensitive to changes in their osmolar environments. In this study, we combined survey, experimental, and demographic modeling approaches to evaluate the possible effects of road salt on two common vernal-pond-breeding amphibian species, the spotted salamander (*Ambystoma maculatum*) and the wood frog (*Rana sylvatica*). We found that in the Adirondack Mountain Region of New York (USA), road salt traveled up to 172 m from the highway into wetlands. Surveys showed that egg mass densities of spotted salamanders (*A. maculatum*) and wood frogs (*R. sylvatica*) were two times higher in forest pools than roadside pools, but this pattern was better explained by road proximity than by increased salinity. Experiments demonstrated that embryonic and larval survival were reduced at moderate (500 mu S) and high conductivities (3000 mu S) in *A. maculatum* and wood frogs (*R. sylvatica*) were two times higher in forest pools than roadside pools, but this pattern was better explained by road proximity than by increased salinity. Experiments demonstrated that embryonic and larval survival were reduced at moderate (500 mu S) and high conductivities (3000 mu S) in *A. maculatum* and at high conductivities in *R. sylvatica*. Demographic models suggest that such egg and larval stage effects of salt may have important impacts on populations near roads, particularly in the case of *A. maculatum*, for which salt exposure may lead to local extinction. For both species, the effect of road salt was dependent upon the strength of larval density dependence and declined rapidly with distance from the roadside, with the greatest negative effects being limited to within 50 m. Based on this evidence, we argue that efforts to protect local populations of *A. maculatum* and *R. sylvatica* in roadside wetlands should, in part, be aimed at reducing application of road salt near wetlands with high conductivity levels.

Some causative agents of amphibian declines act synergistically to impact individual amphibians and their populations. In particular, pathogenic water molds (aquatic oomycetes) interact with environmental stressors and increase mortality in amphibian embryos. We documented colonization of eggs of three amphibian species, the wood frog (*Rana sylvatica*), the green frog (*Rana clamitans*), and the spotted salamander (*Ambystoma maculatum*), by water molds in the field and examined the interactive effects of road deicing salt and water molds, two known sources of mortality for amphibian embryos, on two species, *R. clamitans* and *A. maculatum* in the laboratory. We found that exposure to water molds did not affect embryonic survivorship in either *A. maculatum* or *R. clamitans*, regardless of the concentration of road salt to which their eggs were exposed. Road salt decreased survivorship of *A. maculatum*, but not *R. clamitans*, and frequency of malformations increased significantly in both species at the highest salinity concentration. The lack of an effect of water molds on survival of embryos and no interaction between road salt and water molds indicates that observations of colonization of these eggs by water molds in the field probably represent a secondary invasion of unfertilized eggs or of embryos that had died of other causes. Given increasing salinization of freshwater habitats on several continents and the global distribution of water molds, our results suggest that some amphibian species may not be susceptible to the combined effects of these factors, permitting amphibian decline researchers to devote their attention to other potential causes.


The growth and reproduction of the freshwater snail *Physa acuta* (Gastropoda: Physidae) were measured at various salinity levels (growth: distilled water, 50, 100, 500, 1000 and 5000 μS/cm; reproduction: deionized water, 100, 500, 1000 and 3000 μS/cm) established using the artificial sea salt, Ocean Nature. This was done to examine the assumption that there is no direct effect of salinity on freshwater animals until a threshold, beyond which sub-lethal effects, such as reduction in growth and reproduction, will occur. Growth of *P. acuta* was maximal in terms of live and dry mass at salinity levels 500-1000 μS/cm. The number of eggs produced per snail per day was maximal between 100 and 1000 μS/cm. Results show that rather than a threshold response to salinity, small rises in salinity (from low levels) can produce increased growth and reproduction until a maximum is reached. Beyond this salinity, further increases result in a decrease in growth and reproduction. Studies on the growth of freshwater invertebrates and fish have generally shown a similar lack of a threshold response. The implications for assessing the effects of salinisation on freshwater organisms need to be further considered.


Post-restoration wetland sites often do not resemble natural wetlands in diversity or richness of native species, in part due to the influence of stressors such as excess contaminant loads and invasive species. Road salt and the salt-tolerant invasive *Typha angustifolia* are potential wetland stressors for which little is known, although it is thought that high salt contaminant loads can lead to invasion of a plant community by *T. angustifolia*. To understand how an establishing freshwater wetland community responds to NaCl, with regard to both direct and indirect effects (indirect mediated by competition
with *T. angustifolia*), an assemblage of native marsh species was grown from seed in greenhouse microcosms and subjected to treatments of NaCl (0, 100, 250, 500, and 1000 mg/L solutions) and *T. angustifolia* (with and without *T. angustifolia* seed additions) for 194 days. Direct effects of NaCl on final biomass of the native assemblage were observed in the 500 and 1000 mg/L NaCl treatments. Indirect effects of NaCl on final biomass were observed in the 1000 mg/L NaCl treatment. Diversity and species richness decreased slightly with increasing NaCl concentration. Evenness increased slightly with increasing NaCl concentration. Individual species responded differently to NaCl and *T. angustifolia*, suggesting that species composition plays an important role in determining the extent to which NaCl and *T. angustifolia* influence native community establishment. Results from this experiment suggest that road salt runoff should be considered a stressor during site selection and that restoration of sites exposed to high levels of NaCl may be less diverse or contain an assemblage of species different than that intended.


There have been many documented cases of bird mortality along roadsides where salt was applied. Herbivorous and granivorous species, especially, are attracted to salt, probably to satisfy a dietary need. Because mortality appears to be primarily a result of vehicle strikes, most authors have assumed that salt was only indirectly responsible for the deaths-a case of 'fatal attraction' to busy salted roads. Repeated observations of apparent behavioral toxicity along roadsides, as well as new information on the toxicology of oral salt ingestion in birds, now suggest that salt toxicity per se is contributing to the vulnerability of small songbirds to road traffic and perhaps is a direct cause of mortality in some birds. The difficulty of retrieving bird carcasses and the low rate of reporting suggest that kills probably are more widespread and frequent than indicated by documented reports alone. Most known cases of songbird mortality have occurred within a group of birds collectively known as winter finches belonging to the subfamily Carduelinae. This may result from a higher probability of exposure for these species because of their diet and presence in the snow belt but also may reflect a greater ease of detecting mortality incidents in species forming large feeding flocks. The high attraction of salted roads for winter finches suggests that the roads' ecological footprint is very large. We conclude that the importance of road salt as a mortality factor in these species long has been under-estimated by wildlife managers and transport personnel.


Changes in hydrology, water quality and vegetation were evaluated in four palustrine emergent wetland pairs, each including created and reference sites. Located along interstate highways, they were initially sampled in 1988 and again in 1996. Total nitrogen was generally higher in created sites compared to reference sites, as was specific conductivity, with chloride levels exceeding 800 mg/L, apparently related to road salt. Emergent plant cover increased from 30 to 39% at three created sites, and decreased at a fourth, whereas reference sites remained relatively stable. Wetland species richness also increased from 31 to 39 species at created sites and 35 to 42 species at reference wetlands between the surveys. By 1996 there was an increase in invasive species, particularly
Phragmites australis (common reed) and Lythrum salicaria (purple loosestrife). Phragmites increased from <1 to 15% at created sites, while Lythrum increased at one reference site from <1 to 16%. Typha latifolia (common cattail), dominant in the created wetlands in 1988, decreased from 16 to 5% while Typha angustifolia (narrow-leaved cattail) increased from 2 to 10%. At two created sites experiencing increased sedimentation, Phragmites is now dominant or co-dominant with Typha spp., whereas Carex stricta (tussock sedge) and T. latifolia continue to dominate at reference sites. At the one created, permanent flow-through-hydrology wetland, a three-fold decrease in T. latifolia and an eight-fold increase in Phragmites cover have occurred, the latter correlated with sedimentation from road culverts. Increases in alien or invasive species such as Phragmites and Lythrum can serve as indicators of wetland disturbance.


The suspicion that additives to road salt (K₃Fe(CN)₆ multiplied by 3H₂O) are released in the environment has been confirmed experimentally. The toxic effect is influenced by light intensity, water hardness, pH (HCN), and buffer capacity. These factors should be considered in road salt toxicity tests.


The effects of pollution on freshwater macroinvertebrates were reviewed. Several books and two new journals appeared in 1981. A biotic index, a biological water quality index, an index focused on interaction of lake sediments with toxic substances, a modified Hill’s ratio, and use of oligochaetes as indicator species were proposed. Case studies of pollution were described: experimental acidification, urban storm water runoff, road salt, synthetic crude oil, copper, zinc, tannery effluent, and ash. Macroinvertebrates were also affected by alteration of the physical environment of lakes and streams (temperature, stream flow and depth, turbidity, dissolved oxygen concentration, and water level fluctuations) produced by channelization, sedimentation, flash floods, drought, logging, recreational activities, thermal discharge, and urban development. Species distribution was also a function of predation, substrate, vegetation type, flow conditions, available food, water quality, and season. Production was discussed in relation to environmental factors, including trophic status. Invertebrate penetration of the sediments produced significant sediment mixing and phosphorus release. Many invertebrate sampling techniques and methods of statistical analysis were developed.


Kampoosa Bog in Stockbridge, Massachusetts, USA is a 70-ha wetland comprised of calcareous basin fen and red maple swamp bordered, in part, by roads including the Massachusetts Turnpike. High salt concentrations in the ground water (due to the application of deicing salts on the Turnpike) and Phragmites australis colonies appear to be impacting the native vegetation at this site. Sodium and chloride concentrations at Kampoosa Bog are generally below previously published threshold levels for impacting vegetation, although such levels vary by species and in relation to other environmental stress conditions. Giant reed (Phragmites), a salt-tolerant invasive species, invaded the northern portion of the wetland adjacent to the Turnpike and a gas pipeline sometime after they were built in the 1950s. By 1998, Phragmites had formed dense colonies that continued to spread across the wetland, which supports several state-listed rare plant and
animal species. High salt concentrations (Na$^+$ > 112 mg/L, Cl$^-$ > 54 mg/L) are present up to 300 meters from the Turnpike. *Phragmites* colonies occur in areas with high and low salt concentrations, and the species abundance is not well-correlated with elevated salt levels. Although high salt concentrations and *Phragmites* abundance do not seem to produce an interaction effect on the vegetation of the wetland, the graminoid fen community is impacted by both factors separately. We attribute decreases in the abundance of species between invaded and non-invaded areas to the presence of *Phragmites*. In the graminoid fen, we attribute decreases in both community measures (richness, evenness, and overall cover) and individual species abundances to high salt concentrations.


Vast networks of roads cover the earth and have numerous environmental effects including pollution. A major component of road runoff in northern countries is salt (mostly NaCl) used as a winter de-icing agent, but few studies of effects of road salts on aquatic organisms exist. Amphibians require aquatic habitats and chemical pollution is implicated as a major factor in global population declines. We exposed wood frog tadpoles to NaCl. Tests revealed 96-h LC$_{50}$ values of 2636 and 5109 mg/l and tadpoles experienced reduced activity, weight, and displayed physical abnormalities. A 90d chronic experiment revealed significantly lower survivorship, decreased time to metamorphosis, reduced weight and activity, and increased physical abnormalities with increasing salt concentration (0.00, 0.39, 77.50, 1030.00 mg/l). Road salts had toxic effects on larvae at environmentally realistic concentrations with potentially far-ranging ecological impacts. More studies on the effects of road salts are warranted.


Despite their protected status, aquatic ecosystems of Banff National Park have been subjected to a number of human stresses. Largely as the result of stocking programs earlier in the century, 10 species of nonnative fishes now occur in the Park, while one endemic subspecies of fish has been extirpated, and 2 other species are threatened. A number of rare invertebrates occur in hot springs and caves, including one mollusk that is endangered. Key invertebrates were extirpated from a number of fishless lakes by stocked fish, and in some cases have not returned, even though fishes did not survive. Restoration efforts in 2 small alpine lakes are described. Addition of nutrients and road salt have changed the chemical nature of the Bow River and its tributaries, and caused incidence of benthic algal mats to form in some sections. Impoundment and diversions affect over 40% of the Bow River catchment within the Park. Airborne organic contaminants concentrate in glaciers and high elevation snowpacks, yielding amounts high enough to contaminate fisheries to levels that in some cases approach guidelines for human consumption.


The accumulation of salt and visible injuries on Scots pine needles (*Pinus sylvestris*) were investigated in a field study during two years 1992-1994. Two sampling plots 4 km apart along the Highway 9 in eastern Finland were selected. At Savo-Karjala region, the use of road salt was reduced to about one tenth from normal (slightly salted site), whereas, the use of road salt continued normally at the Central Finland region (heavily salted site). Current, one-year and two-year-old needles were sampled eight times during
Visible injuries in the pine needles were recorded and sodium, chloride and calcium concentrations analysed. During the two-year study, reduced use of deicing salt clearly reduced the accumulation of salt components, sodium and chloride, and induction of visible injuries in the pine needles growing closest to the roadside. No changes in needle calcium concentrations were observed. In the sampling plot along the heavily salted site, browning and premature needle loss was detected especially during late spring. Deleterious effects of road salt did not reach far from the road, since at distances of 20 to 30 m, the salt concentrations and visible injuries in needles were insignificant. Since no changes in soil salt concentrations between sites were observed, aerial salt spray is considered more important to salt accumulation in needles than root uptake. The changes in weather conditions have a significant effect on the accumulation of salt in needles and occurrence of the visible injuries. Great fluctuations in temperature and salt use during winter exacerbate the needle injuries. Thus, the salt concentrations and visible injuries caused by such concentrations of salt should always be considered with respect to the climatic conditions.


A recent study commissioned by Parks Canada on the amphibian populations in wetlands adjacent to the Trans-Canada Highway indicates that amphibian populations seem to be declining and they have disappeared from some wetlands altogether. This study raised concerns that the Trans-Canada Highway, due to its proximity to these wetlands, may be directly or indirectly affecting the amphibian populations. The imminent completion of the twinning of the Trans-Canada Highway through Banff National Park has instigated a search for possible causes for the decline in amphibian populations. This study was undertaken with the express purpose of determining whether or not road salt-contaminated runoff from the highway is making its way into adjacent wetlands and contaminating them. Ten sample sites were established along the Trans-Canada Highway and the Bow Valley Parkway, including one control. Samples were collected in April, June, and September of 2000 and analysed chemically and isotopically. At least two sites appear to be impacted by road salt. However, the effects may not be cumulative due to the calcareous nature of the local bedrock and soils and the large influx of rainfall and uncontaminated snowmelt in late spring.


A study was conducted in 1979-1981 to identify the effects of salt intrusion from a road-salt storage pile on water chemistry and vegetation in Pinhook Bog, La Porte Co, Indiana, and to determine the fate of salt and any resulting yearly changes in water chemistry or vegetation patterns. The impacted area showed salt concentrations as high as 468 milligrams/liter Na and 1215 milligrams/liter Cl within the plant root zone of the peat mat. The salt concentrations in the root zone decreased significantly each year from 1979 to 1981. Analysis of salt movement suggested that the salt was transported vertically downward by water movement through the peat mat following snow melt and heavy precipitation events each spring. Vegetation surveys in 1980 showed an absence of numerous native species in the salt impacted area; these were replaced by invading species. By 1981, many extirpated species had become reestablished in the impacted area after declines in salt concentrations. Salt tolerance studies on Sphagnum recurvum showed reduced growth in length at NaCl concentrations found in the bog.

An uncovered road salt storage pile, located next to Pinhook Bog for 10 years, produced contamination which affected the bog vegetation. Nearly all of the endemic plant species (excluding moat species) were absent from the portion of the bog where mean salt concentrations as high as 468 mg/liter sodium and 1215 mg/liter chloride were measured in the interstitial waters of the peat mat. Skeletons of dead tamaracks with invading cattails and other nonbog species were evident. Over the 4-year study salt concentrations decreased by 50%, and the vegetation composition changed. Some of the invading populations (such as cattails) declined; others continued expansion. During this period many of the endemic bog plants, including Sphagnum, returned to the impacted area. The species present at the end of the study (1983) were salt tolerant and pioneers in secondary succession of disturbed bogs.


A five-year study was conducted to identify the effects of road salt intrusion on the water chemistry of Pinhook Bay following operation of an uncovered salt storage pile adjacent to the bog for ten years. A distinct pattern of elevated salt concentrations was observed in the interstitial waters of the surface peat that corresponded to observed alterations in the bog vegetation. Yearly mean salt concentrations as high as 468 mg/l sodium and 1215 mg/l chloride were recorded in the plant root zone of the peat mat. The salt concentrations decreased significantly each year from 1979 to 1981 throughout the impacted area. Some increases of a lesser magnitude occurred in 1982 and 1983. Analysis of salt movements suggested that vertical transport by water movement was responsible for concentration changes. The major decline in salt levels occurred in the spring following snowmelt and heavy precipitation events. Evapotranspiration during periods of drought resulted in the gradual increases in surface peat salt concentrations. Diverted highway runoff was the major continuing source of sodium chloride contamination and was the likely source of the elevated calcium, magnesium, potassium, bicarbonate, and pH levels also observed in the impacted area.


Secondary succession of *Sphagnum* mosses was studied for 7 yr along a belt transect in a bog that had been exposed to sodium chloride highway deicing salts. Laboratory studies on *Sphagnum fimbriatum*, the dominant recolonizing species, were conducted to determine its salt tolerance level and ability to reproduce from spores and fragments across a salt gradient. Vegetative reproduction was also compared with that of four other recolonizing species. *Sphagnum fimbriatum* represented a high percentage of all recolonizing *Sphagnum* and generally began growing on low hummocks in quadrats where the salt content of the interstitial peat pore waters had dropped to about 300 mg/L as chloride. This salt concentration was also found to be the basic tolerance limit for mature plants and reproducing spores and fragments. The success of *Sphagnum fimbriatum* as a pioneer species seems to be associated with its prolific and probable dispersal of spores, its superior vegetative reproduction, its tolerance of mineralized waters, and its ability to grow on hummocks out of direct contact with mineralized waters.

This study examined the benthic macroinvertebrate communities of 20 springs in southeastern Ontario in relation to major water chemical variables and temperature. Significant differences were evident among the spring communities, and a TWINSPAN classification showed three major groups, which were associated with different levels of urbanization and water chemical conditions. Canonical correspondence analysis (CCA) ordinations indicated that the major environmental gradient was related to temperature and NH$_4$ and to two springs adjacent to a landfill site. CCA ordination of a sub-data set excluding these latter two sites together with 3 closely related variables better illustrated the response of spring communities to different levels of urbanization. The strongest relationship to emerge was that between taxon occurrences and chloride, a major contaminant in groundwater in the study area and believed to be derived from road salt. Several taxa were closely associated with high chloride levels (e.g., *Tipulidae* and *Ceratopogonidae*), whereas others occurred only in springs with low chloride levels (e.g., *Gammarus pseudolimnaeus* and *Turbellaria*). The possibility of using spring macroinvertebrates as biological indicators of chloride contamination of groundwater is discussed.

GROUNDWATER IMPACTS


The impacts of deicing practices on surface water and groundwater are assessed in two studies conducted for the Maryland State Highway Administration. The groundwater study focused on three sites in Garrett County, Maryland. The study results indicate that past open-air storage of deicing salts at the Keysers Ridge maintenance facility and the application of deicing salts in the Keysers Ridge, Grantsville, and Finzel study areas are responsible for the increased levels of sodium and chloride observed in the groundwater and soils at these sites. In localized parts of each study area, the levels of chemicals in groundwater exceed Maryland drinking water standards for chloride and recommended standards for sodium. Preliminary groundwater travel times of less than 10 years have been calculated for each study area. The travel times of solutes are expected to be longer due to the lag time created by retardation processes. In general, the occurrence of groundwater contamination in the study areas is a function of the following factors: (1) aquifer hydraulic properties, (2) proximity to the source of contamination, (3) construction characteristics of wells and physical characteristics of springs, (4) local surface topography and roadway drainage, and (5) type of flow regime (porous flow or fracture flow). The second study on Chesapeake Bay tributaries was conducted to assess the effects of deicing practices on surface waters drained by the Chesapeake Bay. The data suggest that the relatively larger loads of salt entering the streams during the deicing season have little or no impact on the water quality with respect to existing water quality standards in Maryland. The greatest impacts of deicing chemicals occur in small drainage basins which receive large salt loads.


The impact of road salt on a wellfield in a complex glacial moraine aquifer system is studied by numerical simulation. The moraine underlies an extensive urban and industrial landscape, which draws its water supply from > 20 wellfields, several of which are approaching or have exceeded the drinking water limit for chloride. The study investigates the mechanisms of road salt infiltration, storage, and transport in the subsurface and assesses the effectiveness of mitigation measures designed to reduce the impact. The three-dimensional transport model accounts for increases in salt loading, as well as growth of the urbanized area and road network over the past 50 years. The simulations, which focus on one impacted wellfield, show chloride plumes originating mainly at arterial roads and migrating through aquitard windows into the water supply aquifers. The results suggest that the aquifer system contains a large and heterogeneously distributed mass of chloride and that concentrations in the aquifer can be substantially higher than the concentrations in the well water. Future impact scenarios indicate that although the system responds rapidly to reductions in salt loading, the residual chloride mass may take decades to flush out, even if road salting were discontinued. The implications with respect to urban wellfields in typical snow-belt areas are discussed.


The groundwater systems of two areas in Wisconsin, the first relatively pristine, the second urbanized, were studied to determine how these groundwater pathways are vectors of salt and other potential contaminants into lake systems. Groundwaters were the major pathway for chloride contamination to northern Wisconsin glacial lakes that lack...
surface inlets and outlets. Current loading rates to Sparkling Lake are approximately one ton of road salt per year. Modeling results were consistent with the initiation of road salting begun in the late 1950’s. More dramatic increases in chloride concentration in Lake Mendota, near urbanized Madison, result from the significantly greater inputs of salt per unit drainage area. Increases in well chloride levels parallel the lake concentration, suggesting a coupling of these two systems or response to a common input. Ion exchange processes occurring in groundwater systems are all important. All observed lakes and groundwaters demonstrate lower sodium to chloride (Na/Cl) ratios predicted from direct addition of salt in these systems. Exchange processes have long been recognized as the cause for these changes, but the fact that lakes and wells show this departure from Na/Cl ratios of 1 indicates that these waters have experienced exchange in transit to the lakes or wells. Concentrations in lakes will not likely exceed regulatory limits, but groundwater concentrations can be significantly higher, causing concern for: (1) public and domestic drinking water supplies obtained from wells; and (2) terrestrial and aquatic plants whose root systems can be affected by higher concentrations of chloride.


High school sophomores residing in a community with elevated levels of sodium in the drinking water (108 mg/l) exhibited a marked upward shift in blood pressure distribution patterns for systolic and diastolic pressure when compared with students in an appropriately matched community with low sodium levels (8 mg/l). The females exhibited a blood pressure distribution pattern characteristic of persons 10 years older while for males the upshift was similar to that of a group approximately 2 years older. The data suggest that elevated levels of sodium in drinking water may exert an adverse effect on normal healthy persons.


Runoff from large quantities of deicing salts can contaminate groundwater. Tests of water samples from shallow wells in 1967, 1968, and 1973 document the loss of a water supply in an Indianapolis, Indiana, suburban housing development. In 1966 a salt company taking advantage of the location relative to the transportation net of the region, established a distribution point for highway deicing salts at stout field in Indianapolis, Indiana. The salts, only partially protected from the elements, were stored on the southwest end of the abandoned southwest-northeast runway. Runoff from any freshet or storm carried salt to the south and contaminated a shallow aquifer. Investigations by state and city health officials led to removal of the salt. With the salt removed, the same processes which led to the problem aided in flushing and dilution of the high chloride.
water. In a little over a year’s time, dilution by rapid recharge of storm water into the shallow aquifer had reduced the chloride content of the water to a palatable level. Five years after the salt was removed, the chloride level is approaching acceptable limits.


The results from a 1 1/2-year study of groundwater quality in the vicinity of Milwaukee, Wisconsin, supported the suggestion by other researchers that chloride and sulfate are the principal products of urbanization which alter groundwater chemistry. In addition to chloride and sulfate, groundwater samples from the Menomonee River Watershed contained relatively high concentrations of ammonium, fecal coliform, and fecal streptococci bacteria. Field data suggested that contamination of groundwater is caused by infiltration of surface water polluted by municipal and industrial wastes and (or) leakage from sewer lines. Some additional chloride contamination by infiltration of road salt was also suggested.


Buckingham Township is located in Bucks County, north of the populated suburbs of Philadelphia. Development pressures are primarily housing developments which are serviced by onsite septic systems. During the period from 1978 to 1979, 118 groundwater, stream, spring, and precipitation water samples were collected. Water samples were analyzed for Ca, Mg, Na, K, Cl, SO₄, HCO₃, NO₃, PO₄, and SIO₂. Samples were collected from random locations to characterize the water quality of the Stockton Formation aquifer and from specific locations to determine the seasonal variance in water quality. The principal cations were Ca and Na and the principal anions were HCO₃ and Cl. Cultural activities in the area underlain by the Stockton Formation were found to affect the concentration of Cl, Na, and NO₃. Water quality degradation was minimal, except in areas of point-source pollution associated with septic system failures. Thirty-eight percent of the wells sampled had NO₃ concentrations less than 5 ppm, and 7% exceed 45 ppm. The mean NO₃ concentration in stream groundwater and precipitation was 12.2 and 12.9 and 1.4 ppm respectively. The high percentage of groundwater samples with NO₃ concentrations less than 5 ppm indicate that groundwater has not been adversely affected by present land use and impacted areas tend to be point-source problems. The average Cl concentrations for groundwater, stream water, and precipitation was 13.0, 9.9 and 2.4 ppm, respectively. Regression analyses and Na:Cl ratios indicate that halite and Na-Feldspar weathering are the principal sources of Na and Cl. Mass balance calculations of Cl for the Stockton Formation aquifer indicate an approximate loading of 1 times 10 to the 8th grams/yr in the study area. The principal sources of Cl were identified as precipitation, road salt, and domestic sewage.


The use of salt for road deicing has caused increases in chloride concentrations in ground- and surface-water resources. Concentrations of chloride in excess of water-quality standards have been measured in watersheds adjacent to interstate highway 93 (I-93) in southern New Hampshire (NH). A proposed widening plan for I-93 has raised concerns over potential increases in chloride. To formulate a load reduction plan, the NH
Departments of Environmental Services and Transportation are working to identify sources of chloride and develop an understanding of chloride fate and transport in the hydrologic system, as part of a total maximum daily load study. As part of this effort, road-salt contaminated ground-water discharge was mapped in the fall of 2006 to identify potential sources of chloride during base-flow conditions in Policy Brook. This brook drains a small watershed (10.2 square miles) of mixed land use (wooded, residential, commercial, and highway) with multiple sources of salt contamination. The area is underlain by a thin (20 feet) surficial sand layer and basal till, which are underlain by fractured crystalline bedrock. Streamflow in Policy Brook ranged from 0.59 to 515 cubic feet per second from February to November of 2006. Measurements of specific conductance showed high levels (1.3 millimhos/centimeter (mmhos/cm)), about 5 times background, during periods of base flow, indicating a ground-water source of road salt. Electromagnetic (EM) terrain induction conductivity surveys were performed along the longitudinal axis of Policy Brook to facilitate mapping of road-salt contaminated ground-water discharge. Three different EM tools were used that probed slightly different depths below the streambed (ranging from 0 to 12 feet). Results from the three tools showed good agreement and identified several reaches where high conductivity ground water may have been discharging. EM conductivity values ranged from 10 (typical background value for sand) to 300 mmhos/meter in the streambed of Policy Brook. Based on the delineation of high EM values, seven streambed piezometers were installed to sample streambed pore water. Specific conductance in the pore water ranged from 0.64 to 26 mmhos/cm. Locations with high specific conductance in streambed pore water matched well with locations with high EM-conductivity values.


Recent deployments of continuous (USGS real time) specific conductance sensors at a number of monitoring sites in Eastern Massachusetts yield robust datasets of specific conductance, streamflow, and water temperature for every 15 min time interval. This paper presents findings of a study for a site located near an interstate multilane highway (I95/RT128 corridor), exposed in winter months to a heavy road salt loading that has a small perennial discharge flow from a small drainage area. Baseflow values are typically less than 1 cfs. The dataset include 15 min readouts of specific conductance and flow rates for 2005 and 2006 water years. The specific conductance data were inverted to chloride concentrations using an empirical equation (regression of regional data of Cl concentrations and sp. cond.) and a semiempirical equation of Granato and Smith (1999). Dissolved chloride loads, chloride concentrations, and precipitation data were recalculated for 30 min intervals for each water year. Chloride concentration show a uniform pattern/range for baseflow dominated intervals throughout the year usually between 500 and 1000 mg/L. Peak flows in winter have chloride levels in excess of 2,000 mg/L often exceeding 5,000 and occasionally reaching up to 10,000 mg/L. In summer, chloride levels for peak flows fall sharply to 20-50 mg/L range (dilution by overland flows). However, chloride concentrations always return to approximately the same values during the baseflow dominated discharge intervals. No broad scale variations for baseflow are observed. Dissolved chloride loads patterns reflect local hydrological regime, i.e. time intervals of higher dissolved chloride loads coincide with higher flow discharge rates (higher hydraulic gradient). The observed patterns suggest that during the deeper aquifer discharge periods the dissolved chloride load is higher and vice versa. We attribute the observed pattern to sinking of denser saltier water toward the lower aquifer.
zones during the melting of snow banks containing embedded dissolved road salt. Such
ground water recharge process will inevitably result in a density stratified aquifer and
will have long term consequences on mitigations of road salt contaminated aquifers.

Katz, J. 2007. Road salt in bedrock aquifers; is there a problem; Geological Society of America,
Northeastern Section, 42nd annual meeting, Abstracts with Programs - Geological Society of
America, 39, 58.
The use of various chloride compounds for winter road maintenance has been steadily
increasing for decades. Previous research is summarized, and it is seen that the
environmental fate of chloride and the long term impact on bedrock aquifers is poorly
understood. Chloride concentrations in three wells in Maine are compared with water
level data from nearby USGS monitoring wells. The results show a consistent negative
correlation between water levels and chloride concentrations. These observations lead to
the hypothesis that chloride sequestering (accumulation of chloride in low flow or dead
end fractures) is an environmental phenomenon that is actively occurring. Potability of
bedrock aquifers near roads may be at risk for future generations. Potential response of
groundwater professionals is explored.

aquifer used for municipal supply by road salt application; Geological Society of America, North-
Central Section, 23rd annual meeting, Abstracts with Programs - Geological Society of America,
21, 17.
EC measurements, Doctoral thesis, University of Massachusetts at Amherst, Amherst, MA,
United States (USA), United States (USA).

Kelly, W. R. 2001. Temporal changes in shallow ground-water quality in northeastern Illinois:
Preliminary results, Geological Society of America, Programs with Abstracts, 33, A-45.
Northeastern Illinois is one of the most rapidly expanding metropolitan areas in the
country, with a projected population increase of 25% by 2020. Water use increased about
27% from 1980 to 1992 and demand is expected to continue to grow as the population of
the region increases. The principal sources of water in the area, Lake Michigan and deep
bedrock ground water, are being used at their legislated and sustainable limits,
respectively. The only additional source of water to meet the anticipated increases in
water demand are the shallow bedrock and overlying sand and gravel aquifers. This study
is designed to determine temporal changes in water quality in these shallow unconfined
aquifers using historical data. One source of data being evaluated is the Illinois
Environmental Protection Agency's (IEPA) ground-water quality data base. IEPA has
sampled approximately 250 shallow. For positive trends, rates varied between 0.1 and 6.4
mg/L/yr, with a median value of 2.3 mg/L/yr. Background chloride concentrations are
usually < 10 mg/L: approximately 11% of all tested wells and 21% of the shallowest
wells (< 100 ft) had chloride concentrations in excess of 100 mg/L at the last sampling
event. Highest concentrations and greatest rates of change tend to occur in McHenry and
DuPage Counties. It appears that the quality of many of the shallow aquifers in
northeastern Illinois is being degraded.

The rapid expansion of major cities throughout the world is resulting in the degradation
of water quality in local aquifers. Increased use of road deicers since the middle of the
20th century in cities in the northern United States, Canada, and Europe has been linked to degraded ground water quality. In this article, Chicago, Illinois, and its outlying suburban areas are used as an example of the effects of urbanization in a historical context. A statistical study of historical water quality data was undertaken to determine how urbanization activities have affected shallow (<60 m) ground water quality. Chloride (Cl\textsuperscript{–}) concentrations have been increasing, particularly in counties west and south of Chicago. In the majority of shallow public supply wells in the western and southern counties, Cl\textsuperscript{–} concentrations have been increasing since the 1960s. About 43% of the wells in these counties have rate increases greater than 1 mg/L/year, and 15% have increases greater than 4 mg/L/year. Approximately 24% of the samples collected from public supply wells in the Chicago area in the 1990s had Cl\textsuperscript{–} concentrations greater than 100 mg/L (35% in the western and southern counties); median values were less than 10 mg/L before 1960. The greater increase in Cl\textsuperscript{–} concentrations in the outer counties is most likely due to both natural and anthropogenic factors, including the presence of more significant and shallower sand and gravel deposits, less curbing of major highways and streets, and less development in some parts of these counties.

Kivimaki, A. L. 1994. Road salting and groundwater; results of the National Risk Assessment Project; Future groundwater resources at risk; poster papers of the international conference, Suomen Akatemian Julkaisuja = Publication of the Academy of Finland, 4/94, 47-54.


Pathways and fate of road deicing salt (NaCl) applied during the 1994-1995 winter were studied for a 14-km section of a major highway that crosses the Oak Ridges Moraine in southern Ontario. Total salt applications over the winter ranged from 29 to 74 kg/m of highway, and NaCl concentrations in snow banks adjacent to the roadway reached 9400 mg/l during the later stages of snow cover development. This salt was released to the ground surface during snowmelt. Sodium chloride (NaCl) loadings to soil from snow cover during the final melt phase were relatively uniform along the study section (3-5 kg NaCl/m of highway). However, the snowpack at all transects retained <50% of applied NaCl, and this shortfall probably reflected direct runoff and infiltration of saline meltwater from the road surface into the adjacent shoulder and right-of-way. Cation exchange with Ca\textsuperscript{2+} in near-surface soils most likely resulted in preferential retention of Na\textsuperscript{+} relative to Cl\textsuperscript{–}, although total storage of NaCl in upper soil horizons by winter's end was <15% of deicing salt applications. An environmental tracer (\textsuperscript{18}O) was used to trace movement of saline meltwater through the unsaturated zone underlying the highway. Average meltwater particle velocities at a site underlain by loam soils were 0.02 m/d, and ca. 280 mm of water was displaced below a depth of 1 times 86 m over a 78-day period in the spring and summer of 1995. Sodium ion and chloride ion concentrations in water sampled in late summer 1995 at depths >2 m exceeded 500 mg/l and 1000 mg/l, respectively. Approximately 75% of the net flux of NaCl below the upper soil was retained in the 0-2 times 8 m depth interval at this site, and results from more permeable soils traversed by the highway indicate an even greater penetration of the annual NaCl application into the unsaturated zone along the moraine. This saline water likely recharges groundwater in this portion of the Oak Ridges Moraine.
Recent evidence from the mid-Atlantic suggests that freshwater supplies are threatened by chronic chloride inputs from road salts applied to improve highway safety. Elevated chloride levels also may limit the ability of aquatic systems to microbially process nitrate nitrogen, a nutrient whose elevated levels pose human and ecological threats. Understanding the behavior of chloride in urban watersheds where road salts are applied is critical to predicting subsequent impacts to ecosystem health and drinking water supplies. Here we report on a long-term study of water chemistry in Minebank Run, a recently restored stream in an urban watershed of Towson, MD that receives chronic chloride inputs from the 695 Beltway highway and connecting arteries. Chloride, sodium, and specific conductance were greatly elevated in the both surface water and ground water of Minebank Run, spiking in correspondence to road salt application in the winter. Chloride levels were consistently higher in ground water of the bank side of a minor roadway and downstream of the 695 Beltway. Surface water chloride levels remained elevated throughout the year apparently because ground water continued to supply surface water with chloride even after road salt application ceased. Thus, ground water may represent a chronic source of chloride to surface water, thereby contributing to the upward trend in freshwater salinity in urbanizing areas. Stream susceptibility to road salt impacts may depend upon ground water hydrology and stream geomorphology. However, geomorphic stream restoration practices widely used in the mid-Atlantic are not designed to address salinity effects. Source control of road salts may be necessary to reduce environmental risk.


A comprehensive study was carried out to investigate the impacts of road salts on the benthic compartment of a small urban detention facility, Rouge River Pond. Although the pond is an engineered water body, it is representative of many small urban lakes, ponds and wetlands, which receive road runoff and are probable high impact areas. Specific objectives of the study were to document the porewater chemistry of an aquatic system affected by elevated salt concentrations and to carry out a toxicological assessment of sediment porewater to determine what factors may cause porewater toxicity. The results indicate that the sediment porewater may itself attain high salt concentrations. The computations show that increased chloride levels have important implications on the Cd complexation, augmenting its concentration in porewater. The toxicity tests suggest that the toxicity in porewater is caused by metals or other toxic chemicals, rather than high levels of chloride.

Increased concern over the contamination of surface waters by road salts and their adverse effects on the freshwater organisms led to the inclusion of "road salts" on the second Priority Substances List (PSL2) under the Canadian Environmental Protection Act. The list identifies substances that must be assessed on a priority basis to characterize the nature and extent of the risk they pose to the environment or human health. This paper adds to the collection of several reports which constitute "supporting documentation" for the environmental risk assessment of the priority substance "road salts". It reviews the physical-chemical properties of inorganic salts commonly used for road maintenance and their fate and transport in surface waters and sediments, together with the environmental concentrations of road salt constituents in the context of watershed geology and other environmental factors governing their concentrations. The paper also provides a spatial map of chloride concentrations as a basis for developing an understanding of a spatially based, ecological risk assessment for surface water systems and relates the spatial risk map to observed concentrations of chlorides. The data suggest that the surface waters most sensitive to road salts impacts are small ponds and streams draining large urbanized areas. Environment Canada is presently considering several alternatives for dealing with road salts.


Urban development has, historically, been more concerned with the hydraulic characteristics of the drainage systems and technological solutions for controlling floods and pollution than understanding the hydrological characteristics and sustainability of urban catchments. Given the complexity in evaluating the hydrologic behaviour of urban catchments, these systems remain poorly understood and an under-researched field of hydrogeology. Conventional models that solely concentrate on urban runoff as the primary cause of reduced natural recharge do not effectively deal with new sources or pathways of recharge created specifically by urbanization. The hydrologic cycle of Frenchman's Bay watershed, a 27 km² highly urbanized catchment just east of Toronto, Ontario, Canada has undergone a fundamental change in the last 50 years due to increased urban cover. Isotopic hydrograph separation of groundwater and surface waters in stormflow showed that only about 15% of rainfall appears as overland flow and that groundwater accounts for 21% of the total stormflow. Furthermore, it was estimated that 35% of the total rainfall contributes to groundwater recharge. Analytical and numerical models were used to quantify and validate the elements of the urban water cycle. A modified soil moisture balance for the watershed highlighted the significance of localized recharge through preferential pathways. It was found that localized recharge through bypass flow has increased net recharge by about 36%. Moreover, infiltration of roof runoff and physical losses from water mains have essentially maintained urban recharge at preurban levels. Numerical simulations verified increased recharge that occurs following urbanization through onsite infiltration of roof runoff and bypass flow. A chloride mass balance revealed that approximately 50% of road salt applied to the catchment is stored in the shallow subsurface. The presence of oxygen-18 depleted groundwaters with higher bicarbonate concentrations in the most urbanized part of the catchment further substantiates the existence of a highly responsive urban aquifer. The findings of this study have important implications in our understanding of the complex behaviour of urban aquifers including groundwater-surface water interactions and contaminant flow paths.
Groundwater and surface water chemistry in southeastern Michigan is undergoing change as a result of the long-term, land use practice of using sodium chloride (road salt) as a road deicing agent. Groundwater chemistry in the vicinity of major roads and highways is evolving from a Ca-HCO$_3$ type water to a NaCl type water. Persistent plumes of Cl-rich groundwater have been detected in a series of groundwater monitoring wells located nearly one kilometer north of Michigan Avenue, a major eastwest trending highway located in Dearborn, Michigan. Although road salt is only applied as a road deicing agent during the winter months, the long-term impact of this practice is a change in surface water quality as this plume of Cl-rich groundwater discharges to the Rouge River, an important tributary to the Detroit River and a known source of organic and inorganic contaminants to the lower Great Lakes. The analysis of groundwater collected from monitoring wells along the north side of the Rouge River, which parallels Michigan Ave. and along the south side of Michigan Ave. (upgradient wells) show normal Ca-HCO$_3$ type water. These results suggest that Michigan Ave. is the source of the chloride contamination. The spatial variability of the chloride concentrations, for example, higher levels closer to the highway, supports this conclusion.

Elevated concentrations of sodium (Na$^+$) and chloride (Cl$^-$) in surface and ground water are common in the United States and other countries, and can serve as indicators of, or may constitute, a water quality problem. We have characterized the most prevalent natural and anthropogenic sources of Na$^+$ and Cl$^-$ in ground water, primarily in Illinois, and explored techniques that could be used to identify their source. We considered seven potential sources that included agricultural chemicals, septic effluent, animal waste, municipal landfill leachate, sea water, basin brines, and road deicers. The halides Cl$^-$, bromide (Br$^-$), and iodide (I$^-$) were useful indicators of the sources of Na$^+$-Cl$^-$ contamination. Iodide enrichment (relative to Cl$^-$) was greatest in precipitation, followed by uncontaminated soil water and ground water, and landfill leachate. The mass ratios of the halides among themselves, with total nitrogen (N), and with Na$^+$ provided diagnostic methods for graphically distinguishing among sources of Na$^+$ and Cl$^-$ in contaminated water. Cl/Br ratios relative to Cl$^-$ revealed a clear, although overlapping, separation of sample groups. Samples of landfill leachate and ground water known to be contaminated by leachate were enriched in I$^-$ and Br$^-$; this provided an excellent fingerprint for identifying leachate contamination. In addition, total N, when plotted against Cl/Br ratios, successfully separated water contaminated by road salt from water contaminated by other sources.

During the winters of 1974-75 through 1986-87, the Massachusetts Dept. of Public Works (MDPW) applied an average of 198,000 tons of sodium chloride on
Massachusetts highways during winter snow and ice control operations, at an average rate of about 16.5 tons/lane mile/winter. This salt application caused sodium levels in groundwater and water supplies near highways, in some locations, to increase significantly above the natural background level in this area of about 10 mg/L. During the period January 1982 through May 1988, the Massachusetts Dept. of Public Works received 139 complaints of salt contamination of private wells. These complaints were resolved by: (1) well replacement; (2) connection to public water supply; (3) water treatment; (4) highway drainage change; (5) use of salt substitute; and (6) complaint denied. During this period, the MDPW was provided with $2,500,000 by the state legislature, for investigation and remediation of salt contamination of water samples. In 1986, there were 73 public water supplies in Massachusetts with sodium levels above 20 mg/L. The increase, above background, of sodium in some of these water supplies was, at least partially, from the use of highway deicing salt. Complaints of salt contamination of public water supplies are resolved by: (1) reduced salting on state highways in the vicinity of the public water supply; (2) special attention given to salt handling and storage practices at maintenance facilities; (3) installation and operation of scavenger wells; (4) construction of special highway drainage systems to collect the highway runoff and carry it away from sensitive areas; and (5) complaint denied.

Post, R. E. 1980. Ground-water contamination near a road salt storage site in Coventry Township, Summit County, Ohio, Master's thesis, University of Akron, Akron, OH, United States (USA), United States (USA).


The Cambridge, Massachusetts, drinking-water supply system is noted for its elevated chloride concentrations (100 to 150 mg/L dissolved chloride) in the distributed residential water. The system consists of two primary storage reservoirs, namely Hobbs Brook reservoir and Stony Brook reservoir, both located in close proximity to I95/Rt.128, a multilane highway. Fresh Pond reservoir is an intermediate transfer reservoir with no surface water inlet or outlet (kettle pond). Surface water stored at Hobbs and Stony Brook reservoirs is first pumped into Fresh Pond reservoir, then conditioned in the Fresh Pond treatment plant followed by distribution into the public water supply network. This study evaluates the impact of the winter application of road salt on water quality around the source area for the Cambridge drinking-water supply system. Chloride responses, calculated from the specific conductance data, water temperature variation and precipitation events were evaluated for signs of road salt migration patterns. A particular emphasis is placed on the most recent two years of specific conductance, stream-flow, and water temperature data. Utilization of data from six real-time monitoring stations located around Hobbs Brook and Stony Brook reservoirs allows for 15 minute examination of the specific conductance which relates to the amount of sodium and chloride, two main constituents of road salt that are responsible for the deterioration of water quality. The data indicate that salt-bearing highway runoff is responsible for the observed high chloride concentrations that range from 500-2500 mg/L at Cambridge Reservoir Unnamed Tributary 2, near Lexington, MA. Furthermore, the persistent high concentrations of chloride measured at the stations over the course of an entire year suggests that the road salt contamination is extensive through out the region.

Two water-quality studies were done on the outskirts of the Detroit metropolitan area to determine how recent residential development has affected ground-water quality. Pairs of monitor and domestic wells were sampled in areas where residential land use overlies glacial outwash deposits. Young, shallow waters had significantly higher median concentrations of nitrate, chloride, and dissolved solids than older, deeper waters. Analysis of chloride/bromide ratios indicates that elevated salinities are due to human activities rather than natural factors, such as upward migration of brine. Trace concentrations of volatile organic compounds were detected in samples from 97 percent of the monitor wells. Pesticides were detected infrequently even though they are routinely applied to lawns and roadways in the study area. The greatest influence on ground-water quality appears to be from septic-system effluent (domestic sewage, household solvents, water-softener backwash) and infiltration of stormwater runoff from paved surfaces (road salt, fuel residue). No health-related drinking-water standards were exceeded in samples from domestic wells. However, the effects of human activities are apparent in 76 percent of young waters, and at depths far below 25 feet, which is the current minimum well-depth requirement.


As part of the USGS National Water-Quality Assessment, two water-quality studies were done on the outskirts of the Detroit metropolitan area, where subdivisions overlie a shallow, unconfined aquifer. Well pairs consisting of shallow monitor wells and deeper domestic wells were sampled to determine how recent residential development affects ground-water quality. In the study area, seventy-six percent of the ground waters recharged since 1953 have been affected by road salt, septic-system effluent, or fertilizer. This conclusion is based on (1) the relations between inorganic-ion concentrations, well depth, and ground-water age and (2) Cl/Br ratios. Upward migration of deep-basin brine is not an important source of salinity in the young, shallow waters. Very low concentrations of volatile organic compounds were detected in more than half of the monitor wells. Pesticides were detected infrequently and at very low concentrations, despite the fact that lawns and roadways are well maintained. No current health-related USEPA standards were exceeded in waters from domestic wells. However, the effects of human activities are apparent in ground water from below 25 feet, which is the current minimum-depth requirement for wells in Michigan.


A survey of 23 springs in the Greater Toronto Area (GTA) of southern Ontario recorded chloride contamination levels, resulting from the winter application of road de-icing salt, ranging from 1200 mg/l. Chloride level measured in spring water was far more seasonally stable than that measured in surface (river) water, and thus the spatial pattern of Cl contamination indicated by the former was judged to be more reliable. Chloride contamination of groundwater in the GTA was strongly related to urbanisation, and at the four most affected springs increases of between 21 and 34% were detected over the period November 1996 to November 1997. The response of macroinvertebrates living in
these springs to increasing salinity was examined with the aim of creating a biological index of contamination: the Chloride Contamination Index (CCI). A power function yielded a significant correlation between this index and the mean Cl concentration measured at each spring. Taxa were able to be categorised as either "tolerant" or "non-tolerant" of high Cl although none was unique to either end of the scale. However, from both field observations and salinity tolerance trials in the laboratory, the amphipod *Gammarus pseudolimnaeus* was found to be associated with source aquifers only mildly contaminated with Cl. Absence of this species from a spring, particularly if nymphs of the stonefly *Nemoura trispinosa* are present should indicate moderate to high contamination.
AIR QUALITY IMPACTS


Data from the speciation trends network (STN) was used to evaluate the amount and temporal patterns of particulate matter originating from local industrial sources and long-range transport at two sites in Detroit, MI: Allen Park, MI, southwest of both Detroit and the areas of heavy industrial activity; Dearborn, MI, located on the south side of Detroit near the most heavily industrialized region. Using positive matrix factorization (PMF) and comparing source contributions at Allen Park to those in Dearborn, contributions made by local industrial sources (power plants, coke refineries, iron smelting, waste incineration), local area sources (automobile and diesel truck) and long range sources of PM$_{2.5}$ can be distinguished in greater Detroit. Overall, the mean mass concentration measured at Dearborn was 19% higher than that measured at Allen Park. The mass at Allen Park was apportioned as: secondary sulfate 31%, secondary nitrate 28%, soil 8%, mixed aged sea and road salts 4%, gasoline 15%, diesel 4%, and biomass burning 3%. At Dearborn the mass was apportioned as: secondary sulfate 25%, secondary nitrate 20%, soil 12%, mixed aged sea and road salts 4%, gasoline 20%, diesel 8%, iron and steel, 5%, and mixed industrial 7%. The impact of the iron and steel, soil, and mixed aged sea and road salt was much higher at the Dearborn site than at the Allen Park site, suggesting that close proximity to a local industrial complex has a direct negative impact on local air quality.


Concentrations of chloride aerosols in the atmosphere have been measured on a daily basis using dichotomous samplers at one urban and one rural site near Leeds, West Yorkshire. For two periods during the 18 month sampling programme major marine cations (Na$^+$, Mg$^{2+}$) in the aqueous extracts of the filters were analyzed in addition to other common ions. The contributions of marine aerosol to the coarse and fine mass fractions were 10-20% and 2-3%, respectively even though the sites were some 100 km from the sea. The displacement of Cl$^-$ from marine aerosols was clearly demonstrated. Road salt can dominate the coarse mode in winter under certain meteorological conditions. Fine chloride, essentially NH$_4$Cl aerosol derived from combustion-generated HCl and atmospheric ammonia, shows a marked seasonal dependence attributed to the thermodynamics of the NH$_3$ + HCl identical with NH$_4$Cl equilibrium and the relative concentrations of atmospheric NH$_3$ and HCl. Of the total Cl$^-$ aerosol measured at Leeds, about 2/3 was of marine origin.
WATER QUALITY IMPACTS


Willow Brook receives runoff from Cooperstown, NY and flows into Otsego Lake, a phosphorus limited, mesotrophic waterbody. Between 1992 and 1998, the Village of Cooperstown's winter road management policy included plowing and applying abrasives mixed with enough salt to minimize clumping. Between 1998 and 2002, Ice Ban Magic (TM) and Magic Minus Zero (TM), both organic deicers mixed with magnesium chloride, were applied experimentally in conjunction with abrasives and salt. During the winter of 2002/2003, road treatment consisted solely of applications of salt which had been treated with Magic Minus Zero (TM). Precipitation-based monitoring on Willow Brook conducted between 1991 and 2003 revealed significant declines in the export of total phosphorus, despite elevated phosphorus levels in Ice Ban Magic (TM) and Magic Minus Zero (TM), and suspended sediment as the volume of abrasives applied to roads was reduced. Chloride levels are increasing, however. The implicit trade-offs between potential pollutants and the cost of road management in cold climates is acknowledged for management of transportation safety.

The use of chemicals for roadway deicing, the environmental effects of these applications, and approaches for mitigating effects on receiving bodies are discussed. The book is divided into five major sections: (1) information on legal aspects, application technology, and environmental impacts of chemical deicers as well as proposed legislation directed to developing more effective economic and environmental strategies to select appropriate deicing chemicals; (2) descriptions of the environmental impacts of chemical deicers on aquatic and terrestrial organisms as well as on surface and groundwater; (3) data on corrosion effects from various chemical deicers and new salt based deicers with improved anti-corrosive properties; (4) the comparative costs and benefits of salt and calcium magnesium acetate (CMA) and methods to reduce the cost of producing CMA; and (5) descriptions of field applications of chemical deicers, ranging from pavement shear strength experiments and undercutting and disbondment studies to methods for remediating deicing salt contamination of drinking water aquifers and winter highway maintenance procedures.


Releases of salt to land often occur in association with activities such as oil & gas production, salt/sand processing & storage facilities, rendering plants, runoff from snow removal dumps, and transportation of saline material for industrial use. This document is designed to assist those involved in the prevention, assessment, remediation, and management of salt-contaminated sites. It contains information on relevant regulatory considerations in Alberta, including notification requirements & remediation objectives; site assessment & remediation procedures; and risk assessment procedures. The appendix provides background on such topics as sources of salt, naturally occurring saline soils, movement of salts in soil & groundwater, and effects of salt on soil & vegetation.

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We present a characterization of current state of surface water, changes in time and dependence on land use, precipitation regime, and possible other natural and human influences based on data from the USGS National Water Quality Assessment (NAWQA) Program for New England streams. Time series analysis is used to detect changes and relationship with discharge and precipitation regime. Statistical techniques are employed to analyze relationships among multiple chemical variable monitored. Analysis of ion concentrations reveals information about possible natural sources and processes, and anthropogenic influences. A notable example is the increase in salt concentration in ground and surface waters, with impact on drinking water quality. Salt concentration increase in water can be linked to road salt usage during winters with heavy snowfall and other factors. Road salt enters water supplies by percolation through soil into groundwater or runoff and drainage into reservoirs. After entering fast-flowing streams, rivers and lakes, salt runoff concentrations are rapidly diluted. Road salt infiltration is more common for groundwater-based supplies, such as wells, springs, and reservoirs that are recharged mainly by groundwater. The overwhelming variation is attributed to a large compositional range of Na and Cl seen even if all data are combined into a single dataset. Second components are typically associated with dilutions by overland flows (non winter months) and/or increased concentrations due to evaporation (summer season) or overland flows (winter season) if a snow storm is followed by the application of deicers on road surfaces. The last two components reflect the relative dominance of the composition of the local bedrock on groundwater chemistry or the effect of nutrient cycling.


Using our data and data from the USGS National Water Quality Assessment (NAWQA) Program for New England streams, we present a characterization of current state of surface water, changes in time and dependence on land use, precipitation regime, and possible other natural and human influences. Time series analysis is used to detect changes and relationship with discharge and precipitation regime. Statistical techniques are employed to analyze relationships among multiple chemical variable monitored. Analysis of ion concentrations reveals information about possible natural sources and processes, and anthropogenic influences. A notable example is the increase in salt concentration in ground and surface waters, with impact on drinking water quality. Salt concentration increase in water can be linked to road salt usage during winters with heavy snowfall and other factors. Another example is suggested by magnesium concentrations anomaly in Saugus River. The concentration of Mg was found less than 5 mg/L in most rivers, except in Saugus, where the measured concentrations were mainly higher than 5 mg/L. Also, Ca-Mg data are typically highly correlated in all streams but are uncorrelated in water samples from Saugus River. This anomaly, corroborated with the fact that Saugus was the site of the Saugus Iron Works (approximately 1647-1669), led to further investigation. Magnesium oxide is often used as a lining for furnaces. The use of MgO in furnace bricks at the site and disposal of used bricks in the vicinity of the sampling site for Saugus River water samples might be a source of enhanced Mg in samples that were collected at this site. While this effect is small, the purpose of this study is to illustrate the
value of NAWQA data, statistical analysis and GIS to address water quality issues and improve our understanding of relationship between human activities and environment.


Quag Pond in Gardner, MA is a pond margin peatland exhibiting extreme diversity in vegetation and water chemistry. Both vary with respect to anthropogenic land activity around wetland margins. Railroad tracks border a fen dominated by cattails and sedges. Sedges and sphagnum exist in an acidic fen margin closest to a paved road, and true bog vegetation occurs furthest from activity. Weathering of railroad fill contributes increased amounts of Ca2+ (up to 14.7 mg/L) to the fen and acidic fen margins of the peatland, and salting of paved roads supplies increased amounts of Na+ (up to 20.7 mg/l) and Cl- to the acidic fen and bog. Little calcium is present in the bog margin waters. Variation in sodium and calcium concentrations allow for examination of effects of road salt runoff on peat and plant assemblages. In surface and pore waters, Na+ and Cl- show a 1:1 molar relationship until concentrations exceed 1000 ueq/L (23 mg/L Na+), after which Cl- exceeds Na+. This imbalance show that at high pore water concentrations, Na+ is adsorbed onto peat exchange sites. CEC measurements demonstrate that this effect is short lived if Ca2+ remains high, since polyvalent cations preferentially adsorb onto exchange sites. In fen vegetation peat, high Ca2+ concentrations (4.3-7.6 mg/L) are associated with 37-62% of CEC being Ca2+ and 1-2% CEC being Na+. Only in the true bog vegetation, where 7%) of the sites occupied by Na+. A combination of high sodium (>16.3 mg/L) and low calcium (5%) of the exchange sites. High concentrations of Ca2+ prevent Na+ from occupying exchange sites in the long term. These findings demonstrate that true bogs receiving road salt runoff are more likely to absorb Na in quantities toxic to vegetation whereas fens are less likely to become sodic. Either environment could suffer from salt toxicity should concentrations become high.


The impact of various urban land uses on water flow and quality in streams is being studied by monitoring small streams in the Milwaukee urban area. The responses of an urban watershed and an agricultural watershed to an autumn rainfall of 2.2 cm were compared. Flow from the urban basin showed a substantially greater response to the rain than that from the rural. Dilution, resulting from the greater quantities of surface runoff in the urban watershed, caused lower concentrations of sodium, chloride, calcium, magnesium, bicarbonate, and total dissolved solids in the urban stream. The total quantity of these materials removed per unit drainage area of the urban basin was much greater, however. Road salt was still among the dominant dissolved materials in the urban water chemistry seven months after the last road salting. Sodium was apparently being released from adsorption by clays in the urban basin. Suspended sediment concentrations and total loads were higher in the urban stream.


Man-made lakes have significant impacts on the hydrologic conditions in the watershed in which they are built. Reported herein was the examination of the nature of the impact upon baseflow by comparing baseflow conditions at the outlet of the lakes with those elsewhere in the watershed. Situated in the upper reaches of a small watershed, the lakes studied have only a minor effect upon the magnitude of baseflow discharge, increasing it slightly from October to January and decreasing it from May to September. Baseflow quality is affected substantially. Natural dissolved ions, as represented by magnesium, generally are decreased in concentration and total load by the lakes. Road salt related ions are increased substantially in both concentration and total load in the baseflow. Surface runoff stored in the lakes is extremely enriched in salt in the winter, and the storage capacity of the lakes is sufficient to maintain winter salt concentrations in the baseflow near the lakes until summer. The storage effect also tends to damp out seasonal fluctuations in baseflow chloride content which are extreme in suburban watersheds. The difference in quality between lake and non-lake baseflows and the linear distance needed for complete mixing were used as measures of the magnitude and distal extent of the lake effect on baseflow quality.


The effects of an artificial lake system upon the runoff hydrology of a small watershed were determined by comparing the quantity and quality of runoff with those of an adjacent and similar watershed containing no lakes. Lake storage reduced peak discharge and slowed flood recession rate downstream. Water stored within the lakes is generally of different quality than downstream surface runoff. Salt stored in the lakes from winter deicing is released during periods of surface runoff throughout the rest of the year. During summer or fall runoff events, lake outflow dominates the salt load of the outlet stream, generating double-peaked load hydrographs in which the second, or lake-induced, crest is many times large than the peak which corresponds to maximum flow. On the other hand, the lakes cause a reduction of salt loads and concentration in winter runoff. The concentration and loads of ions which are not related to road salt generally are affected less by the lakes, although they are increased substantially in the fall.


This paper presents an approach to examine potential relationships between land use-derived solutes and baseflow surface water quality using regional ground water and solute transport models linked to geographic information systems (GIS). We demonstrate this approach by estimating chloride concentrations in surface water due to road salt transport through ground water in a large coastal watershed in Michigan. The geologically parameterized model for this study provides a good fit to measured hydraulic heads in the watershed and offers a method to estimate spatially and temporally variable solute fluxes via ground water to streams and lakes. The results demonstrate that there is a considerable legacy of land use influencing surface water quality at the study site. The simulated chloride concentrations produced with salted roads as the only chloride source are similar to measured surface water chloride concentrations throughout most of the watershed, except in regions where other sources for chloride (e.g., high-density septic systems, locations of oil brine fields) likely exist. Impacts of other land use related solutes on baseflow surface water quality could also be explored using this...
approach. As a result, watershed managers could be provided with quantitative information about the potential impacts of developments and associated surface-applied solutes on future surface water quality.


Children are at greater risk for adverse health effects from microbial pathogens and chemical contaminants in drinking water. In the first two years, children obtain 70-75% of daily fluid intake from water or reconstituted products. There are many windows of vulnerability during a child’s development when exposure to contaminants can inhibit growth and maturation of organs, metabolic and detoxification systems. Natural source water pollutants include metals, radioactive compounds and microorganisms. Point source discharges contain sewage, pharmaceutical residues and industrial effluents. Non-point urban and agricultural run-offs include feces, pesticides, fertilizers, dumpsite leachates, exhaust particles and road salt. Water treatment plants and distribution systems also introduce harmful reactive compounds. Responses to exposures to low doses of water contaminants are non-linear, developmental and/or multisystemic. Long-term effects of chronic bioaccumulation in utero to adulthood are unknown. Physicians perform key roles by reporting potentially water-borne clusters of diseases and advising about potential hazards. Great Lakes drinking water strategies and policies must provide continuing opportunities for public participation and education. Communities need to play vital roles in multi-stakeholder water management policies.


The chloride ion concentration of local surface water throughout the Greater Boston Area has been rising steadily over the course of the past several decades. This increase coincides with the amount of rock salt applied to the extensive and expanding road system of the area. As traffic increases and public calls for better road surface maintenance are more frequent, more rock salt is used for roadways deicing. This process allows for safer travel and faster recovery from snowfalls. However, the ions present in the crystalline structures of the salts (mostly NaCl with minor CaCl₂, KCl, and MgCl₂) will readily dissolve, dissociate, and enter our surface water and ground water sources. The amount of testing and observation concerning this process has increased over the course of the past 10 years. An ongoing project on the Saugus River near Boston, Massachusetts, monitors the changing water quality of the surface waters. A similar study was started in June, 2005. Its location is a spring in a park on the outskirts of Boston. This project is still underway. This study compares the results of these 2 projects. The chloride ion concentrations have been shown to fluctuate with rainfall, temperature, and rock salt applications in both cases. Calibrated direct relationships between specific conductance and total dissolved solids, chloride and sodium concentrations allow a reliable monitoring of chloride levels in both systems. Saugus River base flow water contains 100 to 150 ppm chloride reaching up to 400 ppm and peak values in excess of 850 ppm during the winter runoffs. Data for the park spring water during its typical
discharge flows have values of 350 to 400 ppm chloride fluctuating with the amount of rain and evapotranspiration. EPA (EPA, 1988) limit for aquatic life chronic exposure to chloride is 230 ppm and for an acute exposure 860 ppm. None of these environments under present conditions is capable to sustain normal aquatic life. The question we face today is what we can do to prevent this problem from escalating in a society that has become so dependant on its roadways.


Ellis, J. B., D. M. Revitt, and N. Llewellyn. 1997. Transport and the environment: Effects of organic pollutants on water quality. J. Chartered Inst. Water Environ. Manage., 11:170-177. The eighteenth report of the Royal Commission on Environmental Pollution made no reference to any potential environmental impacts resulting from runoff pollution associated with transport activities. This paper identifies the magnitude and extent of pollution associated with discharges from various transport sources and identifies solids, metals, hydrocarbons, herbicides and de-icing agents as the principal contaminants of environmental concern. The impacts of these pollutants on the receiving water are reviewed. They are primarily associated with highways which have a high traffic density, and herbicides are considered to be the only potential and widespread hazard to groundwaters. Highway and airport runoff are shown to have both acute and chronic effects on biotic diversity and organism mortality rates, although these effects appear to be largely confined to reaches immediately downstream from the discharge outfalls.

Feick, G., R. A. Horne, and D. Yeaple. 1972. Release of Mercury from Contaminated Freshwater Sediments by the Runoff of Road Deicing Salt, Science, Vol 175, MARCH 10. Addition of NaCl or CaCl₂ increases the relative amount of mercury in the water in equilibrium with sediments by two to five or more orders of magnitude. The effect tends to increase as the mercury burden of the sediments increases. In addition to being a serious contaminant itself, road salt in natural waters can acerbate contamination by mercury and undoubtedly by other toxic heavy metals.


The 1971 assessment of highway deicing salt pollution by the Environmental Protection Agency was the first major study in the United States on the impact of highway deicing salts. It was found that highway salts can cause injury and damage across a wide environmental spectrum. In attempts to provide excellent driving conditions year round, salt was often applied excessively. Uncovered salt storage sites were discovered to be a serious source of ground and surface water contamination. Salts were found to be in high concentrations in highway runoff and were detrimental to water supplies, biota in affected waters, and human health. Damage to roadside soils, trees and other vegetation, roadways, bridges, utilities, and vehicles resulted. Further work was recommended in the study, including: (1) Fostering recognition and awareness of the problem by involvement of government at various levels; (2) beginning detailed long-term studies of the environmental effects of deicing chemicals on groundwater, soils, vegetation, highway structures, and utilities; (3) developing tire designs for icy conditions to reduce deicing requirements; (4) developing remedial measures to restore damaged roadside soils and vegetation and planting salt-tolerant vegetation; (5) developing corrosion-resistant
construction and vehicular materials; and (6) developing substitute materials and alternative technologies for snow and ice removal.


Salt contamination in runoff is generated by storm events. This report presents a state-of-the-art review of highway deicing practices and associated environmental effects and offers a summary of the available information on the following: (1) methods, equipment, and materials used for snow and ice removal; (2) chlorides found in rainfall and municipal sewage during the winter; (3) salt runoff from streets and highways; (4) deicing compounds found in surface streams, public water supplies, groundwater, farm ponds, and lakes; (5) special nutritious or toxic additives incorporated into deicing agents; (6) vehicular corrosion and deterioration of highway structures and pavements attributable to salting; and (7) effects of deicing compounds on roadside soils, vegetation, and trees. Some important conclusions drawn from this study are: (1) deicing salts are found in high concentrations in highway runoff. These salts have caused certain injury and damage across a wide environmental spectrum, and their potential dangers are severe; (2) practically all highway authorities in the US believe that 'bare pavement' conditions are necessary, and this attitude often results in excessive salt application; (3) salt storage sites are persistent and frequent sources of ground and surface water contamination and of vegetation damage; (4) the special additive in road deicers have latent toxic properties and are therefore particularly dangerous; (5) deicing salts have raised the chloride content of water supplies and receiving waters to dangerous levels; (6) deicing salts are a major factor in vehicular corrosion and roadway damage. Rust-inhibiting additives are not effective; and (7) road deicers can disturb soils, trees, and other vegetation comprising the roadside environment. The US Environmental Protection Agency is currently investigating proposals for further research in the area, and has already begun a large project which will produce two manuals—one a deicer users manual, and the other a manual of design and recommended practices for storage facilities and methods of handling deicing materials throughout storage.


The primary deicing chemical used in Michigan is sodium chloride (NaCl), or rock salt. It is inexpensive and easy to store, handle, and distribute. NaCl is effective as a deicer at temperatures down to 10 F. When applied to wet road surfaces, salt dissolves, resulting in runoff to nearby drainage ways and soils. Surface runoff of salt is greater in winter; infiltration into the soil occurs in the spring. When salty water infiltrates the soil, sodium displaces calcium ions, causing the soil to be less fertile, less permeable, and more prone to erosion. Given the mobility of the chloride ion, most of that element moves with the water down into soils or into surface water. Chloride persists in the environment and is not easily removed by chemical, physical, or biological processes. Small lakes and ponds receiving salt runoff, with limited dilution and flushing, experience significant problems, including the release of mercury from lake sediments. Road deicing salts present the most direct threat to groundwaters of shallow, unprotected aquifers. The increase of sodium
and chloride ions in streams and rivers does not pose a serious or immediate threat because dilution limits most problems. However, chloride levels in the Great Lakes have risen significantly in this century, but are still below limits prescribed for drinking water; road deicing salt makes up 11% of the chlorides in Lake Erie, and 40-45% in Lake Michigan. Both the sodium and chloride ions can degrade drinking water, posing a health threat to persons on a salt-restricted diet. Alternatives include using calcium chloride, which is less harmful to highway structures and the environment, calcium magnesium acetate, and abrasives, including sand and cinders.

Gibson, C. E. and D. A. Stewart. 1972. Changes in the Water Chemistry of Lough Neagh Over a 10-Year Period, Limnol. Oceanogr., Pp. 633-635. Statistical treatment of water analyses from Lough Neagh during the period 1958-1968 shows an upward trend in chloride, dissolved solids, and conductivity and a downward trend in color (Hazen value). The increase in chloride is closely paralleled by the increased use of road salt in the catchment area. Although the increase in chloride may explain the increase in conductivity, it is likely that other substances are involved in the increase of dissolved solids.

Gjessing, E., E. Lygren, L. Berglind, T. Gulbrandsen, and R. Skaane. 1984. Effect of Highway Runoff on Lake Water Quality. Science of the Total Environment Vol.33. A small lake close to a main highway in the Oslo area has been studied with regard to water quality. The contribution of pollutants from the surrounding area, from the local atmosphere, and directly from the pavement has been studied and related to the quality of the lake water and the outflowing water. PAH's, heavy metals, and several other quality parameters are evaluated. Studies of lead, cadmium, zinc, and PAH in sediments and bottom organisms are included. The water analyses, including most relevant drinking water parameters, suggest that the contributory brooks to a relatively moderate extent are affected by inorganic highway traffic pollutants, whereas organic pollutants and suspended matter are noticeably high; the washout water from the pavement is rich in inorganic and organic pollutants and suspended matter; the lake acts as a sink most of the year for important pollutants; and the water is significantly affected by chlorides from the road salt. The snow analyses show that during the winter a considerable amount of the pollutants are deposited within 5 m of the road side; that the pollutants are also transported a considerable distance through the air, being traced in the snow even at a distance of 300 m from the highway; and that the concentrations of the inorganic micropollutants in the snow on the lake are more than 10 times higher than in the lake water itself. The sediment analyses show a significant effect on the heavy metal concentration in the upper 2 cm of the sediments, and that these are distributed all over the lake, with a possible maximum in the deeper parts; and that the enrichment of Pb, Zn, and Cd relative to normal is 2-4 fold. The adsorption studies indicate that an essential part of the PAH 's in the drainage water from highway pavement is retained in the soil surface layer. In general the results suggest that important pollutants probably are strongly related to the particulate matter (dust) which is transported through the atmosphere over long distances.

Glenn, D. W.,III and J. J. Sansalone. 2002. Accretion and Partitioning of Heavy Metals Associated with Snow Exposed to Urban Traffic and Winter Storm Maintenance Activities. II, J. Environ. Eng., 128:167-185. Compared to storm water runoff, urban roadway snow exposed to traffic and winter maintenance practices has a much greater capacity to accumulate and retrain heavy metals and other anthropogenic constituents. Heavy metals once released in the
environment are not degraded and partition between the dissolved and particulate-bound fractions. Residence time, solid loadings, alkalinity, hardness, and pH influence partitioning. Accretion and partitioning of Pb, Cu, Cd, Zn, Al, Ca, Na, Mg, and Fe from a series of urban highway sites in Cincinnati, Ohio, are compared to temporal accretion trends at a control site removed from the highway environment. Results from partitioning analysis indicate that Pb, Cu, Cd, Zn, Al, Mg, and Fe were all highly particulate bound, while Na and Ca were mainly dissolved for all highway sites. Partition coefficients for most heavy metals in snowmelt ranged from $10^3$ to $10^6$ L/kg. Concentrations for Pb, Cu, Cd, Zn, and cyanide were orders of magnitude higher than at the control site and exceeded storm water runoff concentrations by one to two orders of magnitude. For residuals analyses, the specific surface area generally increased with decreasing particle size while the predominance of total surface area (SA) was associated with the medium to coarser size fractions. Heavy metal mass trends followed similar general trends to that of the SA. Characterization of accretion and partitioning of these metals is a necessary first step toward development of management and treatment strategies designed to address urban snow pollution.


Ecological studies have demonstrated the adverse effects of road-salt, primarily NaCl, on water quality, flora, and fauna. In this study, we quantified changes in ionic composition and solute flux of water draining the Mohawk River Basin (9103 km$^2$) in New York State, from 1952 to 1998. Using various statistical, graphical, and modeling techniques, we showed that concentrations of Na$^+$ and Cl$^-$ have increased by 130 and 243%, respectively, while other constituents have decreased or remained constant. The use of de-icing salt on roads within the watershed, which we estimate at 39 kg/km$^2$/day, appears to be the primary mechanism responsible for reported increases, accounting for the increase in NaCl export from 16 to 46 kg/km$^2$/day over the 47-year period. Moreover, despite population decline within this rural upstate watershed, increased environmental stewardship, and The Clean Water Act, concentrations of Na$^+$ and Cl$^-$ still increased during the 1990s. Sodium and chloride have increased in the last 50 years in this river ecosystem.


The increased use of forested areas for winter recreation in the mountains has resulted in substantial road development and maintenance activities such as road salting. This study evaluated the influence of road salt on levels of nutrients, heavy metals, and sediment in streams as modified by topography. As a result of an extremely low snow pack, salt inputs and stream discharge were low. This reduced losses of nutrients and salt from the below road areas; however, the losses which did occur were strongly linked to the road salting practice. All study areas showed an accumulation of road salt because of the low discharge. The addition of massive quantities of sodium caused the release of other cations and significantly altered soil structure. The breakdown of soil structure appeared to be the major reason for large losses of sediment and heavy metals from the below road areas. Most streams had very low levels of dissolved heavy metal ions. Because of the low snow pack and discharge it was difficult to evaluate a mulching and revegetation treatment. Most of the differences between watersheds seemed a result of topographic
features. Steep slopes and a large road area to below road area ratio appear most influential in altering water quality.


Of several impacts of road salting on roadside soils, the potential disruption of the nitrogen cycle has been largely ignored. Therefore the fates of low-level ammonium-N and nitrate-N inputs to roadside soils impacted by salting over an extended period (decades) in the field have been studied. The use of road salts disrupts the proportional contributions of nitrate-N and ammonium-N to the mineral inorganic fraction of roadside soils. It is highly probable that the degree of salt exposure of the soil, in the longer term, controls the rates of key microbial N transformation processes, primarily by increasing soil pH. Additional influxes of ammonium-N to salt-impacted soils are rapidly nitrified therefore and, thereafter, increased leaching of nitrate-N to the local waterways occurs, which has particular relevance to the Water Framework Directive. The results reported are important when assessing the fate of inputs of ammonia to soils from atmospheric pollution.


Organic debris dams (accumulations of organic material) can function as “hot spots” of nitrogen processing in streams. Suburban streams are often characterized by high flows that prevent the accumulation of organic debris and by elevated concentrations of solutes, especially nitrate and chloride. In this study we (1) studied the effects of urbanization on the extent and characteristics of debris dams in large and small streams and (2) evaluated the effects if NO$_3^-$ and Cl$^-$ on rates of N cycle processes in these debris dams.


Street salting studies in the Meadowbrook Watershed, Syracuse, New York were described. Over a 3 yr study period, 81.5% of the salts applied left the watershed in runoff waters. Considering the suburban nature of the basin, this was in consonance with results found elsewhere. Chloride concentrations in the low flow months of April-October were found to increase with time, suggesting that salt is accumulating in the local groundwater, which is a source of supply for these low flows.

The use of salt to melt ice and snow on streets and roads has become prevalent throughout the northeast US several states apply as much as 20 tons per lane-mile. Eventually the salt reaches streams and lakes. In Meadowbrook, New York, the chloride content reached a high of 11,000 ppm in December 1969. The runoff from the watershed was emitted in several surges. Chloride concentrations declined with the onset of summer, but still remained high, suggesting that some of the salt applied during the past winter appeared in the summer streamflow. Salt runoff entered a small lake, and flowed directly to the lake bottom. The buildup of high density saline water in the lower portion of the lake prevented complete mixing in the spring. Incomplete mixing led to anoxic conditions in the lower lake strata. The population of benthic fauna of the lake was changed by the flow of salt water into the lake. From a total of 10 species of dipteran larva and oligochaetes, only 4 species remained.

Heiskary, S and E. Swain. 2002. Water quality reconstruction from fossil diatoms: applications for trend assessment, model verification, and development of nutrient criteria for lakes in Minnesota, USA. Environmental Outcomes Division, Minnesota Pollution Control Agency, St. Paul MN.

Diatom reconstructions of historical phosphorus and chloride concentrations and sediment accumulation rate, based on sediment cores from 55 lakes in Minnesota, provide a unique opportunity for examining temporal and spatial trends in eutrophication, validating eutrophication models, and providing historical perspective for developing nutrient criteria. Sediment cores, obtained by a piston corer between 1995 and 1998, were sectioned and dated. Sections corresponding to 1750, 1800, 1970, and 1993 time-periods were used in this analysis. Distinct regional patterns in historic (mean of 1750 and 1800) phosphorus concentrations were evident. For lakes within the Twin Cities Metro Area, change in “built up” land use and percent of the watershed that is roads explained a significant amount of the change in chloride concentrations.


A study was conducted from May 1974 to June 1975 to survey the effects and fates of deicing salts applied along major California highways in the Central Sierra Nevada. The study area centered on Lake Tahoe basin and aquatic ecosystems near a major highway, Interstate 80. Thirty-five routine sampling sites were chosen for their proximity to highways. During the winter, chloride levels in streams below the major freeways were elevated. The high chloride levels occurred after the application of salt to the roads, decreasing as the time from application increased. Small lakes receiving runoff from the major roads were also enriched with chloride. Several of these lakes displayed a temporary chemocline, which was sufficiently strong to stabilize a temperature inversion in one lake. Data are not available which would make it possible to determine whether the lakes showing higher chloride to specific conductance ratios are in equilibrium or are increasing the chloride enrichment. While these lakes in California did not show the dramatic degradation reported for lakes in the Northeastern sections of the United States,
it is suggested that continual and careful monitoring be undertaken in these California lakes


A two-phased study, recently completed for the Toronto area, Canada examined the sub-surface transport of urban contaminants into Lake Ontario. In phase 1, an audit of contaminant sources showed that the release of chemicals from landfills, underground storage tanks, road de-icing salts and agricultural chemicals during the past 30 years has the potential to cause widespread degradation of groundwater quality and impact receiving streams and near-shore areas of the Lake. In phase 2, a groundwater flow model was used to identify groundwater flow paths and estimate contaminant travel times. Modelling showed that while many of these impacts could be sustained within a 100-year time frame, many contaminants, if resistant to biodegradation, may not emerge in surface waters for considerably longer. While changes in land-filling practice and underground storage tank design are likely to limit future additional impacts by many chemicals, practices such as road salting that continue to contribute contaminants to the sub-surface will cause water quality to deteriorate until a chemical steady-state is reached. In the study area, this will take at least 500 years.


Seven rivers in Maine were sampled in April, July and October for a two-year period to determine the effect of highway salting on water quality. The water samples were analyzed for content of sodium and chloride ions. Four of the rivers selected were from the southwestern section of the state because of the relatively high road density and consequent salt usage in that area. Three rivers were from the eastern section of the state where there are few roads. Sodium and chloride concentrations were highest in the rivers in the southwestern part of the state (Androscoggin, Kennebec, Penobscot, Saco), but the concentration never exceeded 11 ppm of either ion. The levels in April at the time of snowmelt were lower (1-4 ppm) than in October. The determinations of sodium and chloride concentrations are tabulated.


Between 15 and 25 tons per mile of salt are supplied to highways in northern states each winter. This results in sodium contamination of soils that threatens vegetation and soil drainage, and chloride contamination of wells and ponds, but has no measurable effect on rivers. At the present time there are no acceptable alternatives to sodium chloride for deicing highways. However, the following steps can be taken to minimize further damage to the roadside environment: (1) Avoid drilling wells too close to highways; (2) Reduce salt use through metering; (3) Select salt-tolerant vegetation for planting along highways; and (4) Exchange sodium ions in soil with calcium ions by applying lime along highways.


Climate, flow rate and land use are all known drivers of water quality in river systems, but determining the relative influences of these factors remains a significant challenge for
aquatic science and management. Long-term data from the Schuylkill River at Philadelphia is assessed here in an attempt to ascertain the separate and combined influence of these major drivers on water quality in a developed watershed. Water quality measures including nutrients, conservative solutes and bacteria all elicited distinct seasonal patterns driven primarily by river discharge. Mass transport rates of sodium and chloride have increased with time, and were elevated in winter, presumably as a function of road salt deposition. A steady increase in developed land area in the watershed has occurred in recent decades, which allowed the use of time as a surrogate parameter for regional development in the construction of multiple factor linear models predicting the relative influences of precipitation, river discharge and developed land area on river water quality. Linear models predicting annually averaged water quality measures showed the effects of precipitation, discharge and developed land area to be of nearly equal importance in regulating levels of conductivity, alkalinity, sodium, and chloride in the river. Models predicting water quality variables for discrete samples demonstrated that river flow was the major determinant of daily variability in alkalinity, conductivity, hardness and calcium levels, while still resolving the highly significant influence of watershed development on water quality. Increases in solute transport in the Schuylkill River in recent decades appear to be the direct result of modern suburban development in the watershed.


A study was conducted in the Catatonk Creek watershed, in the headwaters of the Susquehanna River, Tioga County, NY, in order to determine the vulnerability of the valley-fill aquifers and the Catatonk Creek to nitrate contamination. The overall goal of this research was to evaluate nitrate transport and the retention mechanisms for different combinations of common soil types and agricultural land uses within the Catatonk watershed and to assess the geochemistry of the Catatonk Creek. The secondary objective was to determine whether unsewered septic systems contribute to nitrate load in the Catatonk Creek. In order to address the objectives, a field study was conducted and a numerical model was developed to use as a tool for predicting the long-term effect of fertilizer application as a source of nitrate loading to the underlying aquifer. The results indicate that leaching of nitrate is greater through the Howard Gravely loam than the Tioga Silt loam for all crops. Likewise, the leaching is also greater for the same soil cultivated with alfalfa than when it is cultivated with corn because of the lower uptake of nitrate by alfalfa leaving more nitrate in the soil for leaching. Leaching of nitrate below the root zone was greater during the wet season than during the dry season, with the largest fluxes associated with large rainfall events. Anthropogenic sources in the town of Candor, indicating septic systems and road salt, substantially alter the quality of the Catatonk Creek water. Arsenic, sodium, chloride also showed significant increases in concentration and load from upstream to downstream of the unsewered town. Furthermore, this study highlights major differences in the chemical concentrations and the geology between the headwater streams examined in prior studies and the Catatonk Creek which are associated with the increased agricultural and residential land uses and the glacial-fluvial outwash deposits in the main valley.

Various mechanisms by which metals may be trapped in snow were tested by taking samples in three types of environment—urban, unmineralized rural, and mineralized rural. Snows were sampled in the city of Ottawa and in the vicinity of a mercury prospect near Clyde Forks in eastern Ontario. In January 1971, fresh fallen snow samples collected in Ottawa contained 3.5 to 4.0 ppb hg with a mean of 3.7 ppb. The snow contained scattered soot particles, probably residues of burned fuel oil and gasoline. The elevated hg values probably reflect the hg content of fossil fuels. The prime influence on these metal contents is the proximity of a freeway. Elevated contents of Na, Zn, Pb, Ni, and Fe in nearby fallen snow clearly show that falling snow is an efficient scavenger of airborne dust and aerosols. The metal contents of fresh surface snow in unmineralized areas are much less than in Ottawa. However, snow collected in mineralized zones contains significant Hg, Pb, Zn, Cu and Mn, particularly near to the soils. Metals readily migrate into the snow from underlying mineralized soils. Significant concentration gradients are observed for the ore metals, hg and cu, where 40- to 50-fold differences in metal content are observed across a 5-foot depth of snow.


Any chemical deicer used to clear roadways in winter will eventually be present at detectable levels in the environment. Much of the salt applied eventually infiltrates groundwater aquifers. Increased salt levels in aquifers adjacent to roadways can be linked to the use of deicing salts. Elevated sodium levels in drinking water present a health risk. Mercury and other heavy metals may be liberated from lake sediments through ion exchange processes. Sodium chloride does not have significant deleterious effects on aquatic biota in large or flowing bodies of water where dilution takes place quickly; smaller lakes are more severely impacted. The rate of salt application is positively correlated with salt concentrations found in roadside soils. Salt decreases aeration and water availability in soils through structural changes as sodium replaces calcium in the anion exchange process. Roadside vegetation is damaged because salt places more osmotic pressure on plants. The tolerance of animals to salt water is generally high and increased salt concentrations in ground and surface water are rarely a problem.


Water samples were taken at a point near the lake center at 1-meter intervals from the surface to the bottom and from two primary inlets biweekly from January to October, 1981. Analyses were made for temperature, oxygen, conductivity, pH, alkalinity, chloride, and total phosphates, nitrates and total dissolved solids. While the amount of road salt entering from the lake subdivision was greatly reduced due to lowered use, the lake still receives an appreciable amount of salt runoff each winter. The major inflow is now from the highways north of the lake. Since the movement of saline water is through a small wetland before entering the lake, a more diffuse runoff occurs, apparently facilitating mixing of the saline water throughout the water column, thereby not greatly increasing stability of stratification. Hence, the lake can mix completely in the spring. The lake remains highly eutrophic; total phosphates are high throughout the year, while nitrate levels are greatly reduced. During the summer, nitrates were virtually undetectable. It may be that nitrates have become the limiting factor in the lake. During most of the 1981 winter, chloride concentrations were 150 mg/liter or less, except for one day in February when concentrations at one outflow reached 1250 mg/liter. Two weeks
following, chloride in the bottom meter of water had increased from 96 to 720 mg/liter and the conductivity from 440 to 1000 micro-mhos.


Sodium and chloride concentrations and export increased from 1986 to 2005 in a rural stream in southeastern New York. Concentrations increased 1.5 mg/L per year (chloride) and 0.9 mg/L per year (sodium), and export increased 33 000 kg/year (chloride) and 20 000 kg/year (sodium) during this period. We estimate that salt used for deicing accounted for 91% of the sodium chloride input to the watershed, while sewage and water softeners accounted for less than 10% of the input. Road salt use in the watershed did not increase during the study, but sodium and chloride from sewage and water softeners is likely to have increased slightly due to a small increase in population. Increased input from sewage and water softeners cannot account for the increase in concentration and export from the watershed. Model results suggest that the increase in streamwater concentration and export was likely due to a lag effect of long-term road salt use and subsurface build-up.


Highway deicing activities can influence the quality of waters draining urban areas that experience multiple winter season freeze/thaw cycles. However, because of the flashy hydrology of smaller urban streams, and the unpredictable nature of deicing runoff, these events are difficult to fully document by traditional monitoring approaches. The frequency, duration, intensity and downstream attenuation of highway deicing salt runoff events were captured by remote continuous flow and conductivity monitoring, in combination with dry and wet weather grab sampling, at four stations along a three-kilometer-long unculverted reach of an urban Pennsylvania stream, Nine Mile Run. Base flow dry weather conductivity values along Nine Mile Run averaged 1,232 umhos/cm and could drop as low as 61 umhos/cm following summer storms. However, at a major storm sewer discharge, which drains a highly urbanized and almost completely culverted subbasin of 9.8 km$^2$, short duration winter thaw peak conductivity values as high as 32,457 umhos/cm were documented. While such peaks tended to occur during very minor winter flow pulses, and were highly attenuated by channel storage at downstream stations, the shock loads of salt experienced were sufficiently elevated to cause concern about osmoregulatory stress to freshwater organisms. Even during base dry weather summer flow conditions, the major ion composition of the waters of Nine Mile Run was dominated by sodium chloride, rather than calcium sulfate, as occurs in nearby drainages.


Studies were made in the Sleepers River basin of Vermont during 1968 to 1970 to determine the effects of road deicers on water quality. Streams not influenced by the highway averaged 2 to 5 mg/liter chloride, while concentrations in the stream affected by the highway were about an order of magnitude higher. Salt concentrations in the highway-influenced stream peaked during summer baseflow. Some of the winter's salt apparently contaminated the soil, emerging later in groundwater inputs into the stream. Chloride concentrations in individual seeps sampled near the highway exceeded 200
mg/liter. Annual salt (NaCl) 'background' yields averaged 2.5 metric tons/sq km/yr for control catchments. The basin containing the highway yielded about 75 tons total in excess of background delivery. Since an estimated 67-100 tons of salt was applied within the watershed, much of the salt apparently appeared in the streamflow.


Deicing roads by salting them may or may not reduce accidents, but salting roads definitely does raise the salt level of streams that flow nearby. Highway deicing chemicals, especially sodium chloride, are used liberally during winter months in many areas. The total volume of deicing chemicals used in the US probably exceeds 2 million tons per year. Road salt investigations were carried out in the Sleepers River basin, Vermont, between 1968 and 1970. The topography is rolling, like most of the region, with slopes of 10% to 40% common. Soils are mostly permeable sandy loams and loams several meters deep. A 4-km section of US highway 2 traverses the research basin just west of St. Johnsbury, VT. Salt concentrations in the highway-influenced stream peaked during summer baseflow, not during winter or spring as might be expected. Peak chloride concentrations during the summer dry period indicated that some of the road salt found its way into soils, then into subsurface flows, and finally emerged in summer's groundwater inputs into the stream. Individual seeps sampled near the highway showed chloride levels exceeding 200 mg/liter. Chloride levels in the stream did not exceed 100 mg/liter. Problem concentrations could arise where a salt-contaminated stream empties into a town water-supply reservoir.


A multivariate approach was used to analyze hydrologic, geologic, geographic, and water-chemistry data from small order watersheds in the Quabbin Reservoir Basin in central Massachusetts. Eighty three small order watersheds were delineated and landscape attributes defining hydrologic, geologic, and geographic features of the watersheds were compiled from geographic information system data layers. Principal components analysis was used to evaluate 11 chemical constituents collected bi-weekly for 1 year at 15 surface-water stations in order to subdivide the basin into subbasins comprised of watersheds with similar water quality characteristics. Three principal components accounted for about 90 percent of the variance in water chemistry data. The principal components were defined as a biogeochemical variable related to wetland density, an acid-neutralization variable, and a road-salt variable related to density of primary roads. Three subbasins were identified. Analysis of variance and multiple comparisons of means were used to identify significant differences in stream water chemistry and landscape attributes among subbasins. All stream water constituents were significantly different among subbasins. Multiple regression techniques were used to relate stream water chemistry to landscape attributes. Important differences in landscape attributes were related to wetlands, slope, and soil type.

A study was made of the impact of highway deicing salt on the water quality of Lake George, New York, and three stream basins, two adjacent to the southern end of the lake and one remote basin on the east shore. It was apparent that peaks in chloride delivery rates were associated with peak stormflows as the highest sustained delivery rates were noted in the late spring and early summer and the highest instantaneous deliveries were noted during snowmelt and highway runoff in late winter and early spring. Because Lake George itself showed no variation in chloride concentration with depth, there is no density gradient potential for inhibiting overturn and density imposed stratification is not expected with the present highway system. Although highway deicing salts apparently do have a significant effect on chloride budgets in streams, no adverse water quality impacts were found. However, a potential for groundwater contamination by deicing salt in areas of gentler slopes and poorer soil drainage does exist as a high percentage of deicing chlorides apparently enter the local groundwater; there also appeared to be a wintertime increase in chloride precipitation.


The chemical effects of road-deicing salt on soil and water were studied in five small, forested catchments in southeast Sweden. The use of deicing salt on roads applied during the winter season 1998/99 had a profound effect on the soil and stream water chemistry in the studied catchments. The salt applications caused increased salinity in direct proportion to the accumulated amounts. The added salt also induced ion exchange in the soils between Na and primarily Ca and Mg. In some of the catchments, ion exchange increased the mobility of H$^+$ ions and trace metals such as Zn and Cd, reducing alkalinity and increasing the Zn and Cd concentrations in the streams.

Mercury mobilization off of aquifer sediments by acid rain, road salt runoff and fertilizer solutions is investigated using column and batch equilibria experiments. Sediments from the Kirkwood Cohansey aquifer System, New Jersey are used to determine the mobilization potential of mercury due to changing infiltration water chemistry. In a series of batch equilibria and column experiments mercury contaminated sediments were treated with a dilute nitric acid solutions, 20-20-20 fertilizer, super phosphate fertilizer and dilute sodium chloride solutions. Mercury mobilization is enhanced by solutions containing sodium chloride and 20-20-20 fertilizer. These solutions can remove up to 90% of the mercury sorbed to the sediments. Mercury mobilization by phosphate fertilizer and acid rain proceeds at a slower rate and only 30% of the mercury is removed. It was found that irrigation of the sediments following treatment with 20-20-20 fertilizer or sodium chloride increased mercury mobilization associated with the destabilization of iron and aluminum oxides.

Studies of forested rural watersheds provide estimates of background contamination for comparison with streams and rivers in other settings. We performed a landscape analysis and measured major dissolved ions and benthic macroinvertebrates for a small rural watershed in Albany County, NY, to determine spatial variation in water quality. An estimated 73% of the surface cover is post-agricultural forest, with only 2.3% of the watershed covered by roads and other impervious surfaces. Although water quality was consistently high in most of the creek, we detected three relatively distinct zones separated by impoundments; zonation was most apparent in relative concentrations of major ions, less so with benthic macroinvertebrate community similarity. At ten sample stations, buffer size, measured as upstream land cover and distance to nearest road, did not correlate well with chemical water quality indicators. In particular, we found the highest levels of chloride, indicative of road-salt contamination, in areas of maximum forest buffer. Small feeder creeks that drain nearby roads may function as 'leaks' in otherwise well-buffered watersheds with low road densities.


Potential impacts of road salting on the environment have increased by the introduction of certain stormwater management practices. Specific impacts are discussed for four such practices, infiltration facilities, oil and grit separators, stormwater ponds and constructed wetlands. The main concerns about the hazards of chloride-laden stormwater discharges include contamination of groundwater, leaching out of trace metals, densimetric stratification and poor vertical mixing in ponds, direct and indirect toxic effects, benthic drift and reduced biodiversity. The associated environmental risks need to be reduced by chloride source controls, and prevention of excessive chloride accumulations by appropriate design and operation of stormwater facilities in winter months.


The chemistry of a first-order stream in Amherst, ME, with a catchment area of 103 ha has been strongly altered as a result of road salt application at a rate of approximately 4 t of NaCl per year in the lower 15% of the catchment. Downstream from the road, elevated stream Cl is accompanied by elevated Ca, K, Mg, and Na. The chemistry of the stream was deconstructed to identify the impact of the salt on total stream chemistry. Components quantified include precipitation (including dry deposition), chemical weathering, road salt, and cation exchange. Sodium from the road salt displaces Ca, K, and Mg from the soil on an equivalent basis. The displacement was at a maximum in late Fall and early Spring, indicating a long residence time for the NaCl. The exchange process was reversible. With continued loading of NaCl the water chemistry should reach a steady state such that Na and Cl move through the soil in a relatively conservative way, when the soils are at equilibrium with elevated concentrations of Na. Concentrations of Ca, K, and Mg in stream water should concurrently return to pre-salting values under the new steady state.

A multiple regression model of atmospheric deposition of salt, combined with geographic information systems (GIS) data on four classes of roads, is used to predict sodium concentrations in 162 randomly chosen streams in Massachusetts. All four classes of roads, as well as atmospheric deposition, were found to be highly significant in a model that explains 68% of the observed variation in sodium concentration. The highest salt loading rates are associated with interstate and major state roads with an estimated 22,500 and 17,700 kg of salt per kilometer, respectively. Our mass balance calculations indicate road salt is the major source of salt to the streams in Massachusetts. We examined some of the common statistical problems associated with the use of multiple regression for this type of analysis.

Mattson, M. D., P. J. Godfrey, M. F. Walk, P. A. Kerr, and O. T. Zajicek. 1992. Regional Chemistry of Lakes in Massachusetts, *Water Resources Bulletin* WARBAQ, PP. 1045-1056. Over 2000 lakes were surveyed in the state of Massachusetts (198301984) to examine the spatial variations in their acid-base chemistry. The survey differed from previous surveys by including small lakes and nonpristine urban lakes. The median acid neutralizing capacity (ANC) for samples collected in October 1983 and 1984 was 184 microeq/L and 5.9% were acidic (ANC \(\leq 0\)). Small lakes (< 4 ha) were more likely to be acidic than large lakes. Generally, sulfate was the dominant acidifying agent, although organic anions were dominant in some of the lakes in the Cape Cod region. The ionic composition of the lakes showed strong regional patterns that appeared to be related to geology and human population density. An analysis of variance of ANC shows the six regional categories in the state explain 51% of the variance, while a combined general linear model of lake drainage type, color, elevation, size, silica and hydrogen ion deposition could explain only 4.9% of the variation in ANC. Calcium rich, high ionic strength lakes were present in the marble bedrock in the west, and relatively dilute lakes dominated by sodium and chloride were found near the coast. Chloride concentrations were also related to population density, suggesting road salt as a likely contributing source.

Menking, K. M., A. B. Jost, K. C. Smith, W. B. Salls, and M. A. Cunningham. 2008. Mass balance of chloride from deicing salts in a small Hudson River tributary; Geological Society of America, Northeastern Section, 43rd annual meeting, *Abstracts with Programs - Geological Society of America*, 40:59. Chloride derived from deicing salt is a persistent contaminant in streams of the northeastern United States and other northern localities. Elevated concentrations in summer baseflow indicate that road salt does not merely wash off of roads into storm sewers but also enters the groundwater system through splash off of impervious surfaces. We used a Yellowsprings Instruments sonde in conjunction with a Hobo water level logger to determine the flux of chloride over time in the Casper Creek, a small (18-km long, 31 km²) drainage area) tributary of the Hudson River in Dutchess County, New York. Chloride concentrations ranged from 35 to 230 mg/L and stream discharge varied between 0.03 and 1.2 m³/s over a four month interval from August through November of 2007, yielding a projected annual chloride flux of \(4.5 \times 10^5\) kg in the absence of new winter deicing applications. Using GIS, we determined the total length of roads upstream of the monitoring site, which allowed us to estimate the amount of salt (\(8.9 \times 10^5\) kg/yr as chloride) applied during the previous winter based on lane-mile application rates provided to us from local Department of Transportation agencies. The ratio of projected chloride from groundwater inputs to chloride applied to roadways measures 0.51. Continued monitoring through the winter will allow us to complete a mass balance to determine whether chloride concentrations appear to be increasing, decreasing, or staying...
the same in groundwater. Determining the trend of chloride concentrations is important for aquatic life, which can begin to show chronic impairment at concentrations as low as 250 mg/L, and may point to the need for changes in development practices toward clustered development and other factors that reduce impervious surfaces.


Decreases in exchangeable base cation reservoirs, base cation export, and lake concentrations have been reported for acid-sensitive regions in Europe and eastern North America. These decreases have produced smaller than anticipated increases in alkalinity in surface waters in response to reductions in sulphate emissions and may have ecological consequences. This study presents annual export rates of Ca, Mg, K, and Na from 20 forested catchments between 1978 and 1998 and concentrations in seven downstream lakes between 1975 and 2005 in an acid-sensitive region of central Ontario, Canada. In contrast to monovalent cation export, decreases in divalent cation export continued after an extended dry period ended. Lake concentration trends showed three distinct periods. The first period (1975-1976 to 1982-1983) coincided with high runoff and was characterized by relatively high Ca, Mg, and K concentrations. This was followed by a 10-year period of fluctuations around the long-term mean. Concentrations then dropped below the long-term means and remained 5%-20% below the means until 2004-2005. The latter trend in lake concentrations suggests that export likely remained low but stable after May 1998 (the last month for which export data are available). Na increased between 250% and 350% in Dickie and Harp lakes as a result of road salt contamination.


Mineral acids and bases influence pH largely through their effects on acid-neutralizing capacity (ANC). This influence becomes particularly significant as ANC approaches zero. Analysis of data collected by the Adirondack Lake Survey Corporation (ALSC) from 1469 lakes throughout the Adirondack region indicates that variations in ANC in these lakes correlate well with base cation concentrations (C-B), but not with the sum of mineral acid anion concentrations (C-A), because C-A is relatively constant across the Adirondacks while C-B varies widely. Processes that supply base cations to solution are ion-specific. Sodium and silica concentrations are well correlated, indicating a common source, mineral weathering. Calcium and magnesium concentrations are elevated in the lower waters of some lakes due to reducing conditions. These conditions lead to an ephemeral increase in C-B and ANC. When the lakes mix and oxic conditions are restored, these ions largely precipitate from solution. Sulfate is the dominant mineral acid anion in ALSC lakes. Sulfate concentrations are lowest in seepage lakes, commonly about 40 microeq/L less than in drainage lakes. This low level is due in part to the longer hydraulic detention time in seepage lakes, which allows slow sulfate reduction reactions more time to decrease lake sulfate concentrations. Nitrate typically influences ANC during events such as snowmelt. Chloride concentrations are generally low, except in lakes impacted by road salt.


The effects of salt use for highway deicing and snow removal on water supplies, lakes, and rivers; on trees and other vegetation; on bridges; on vehicles; on underground power transmission lines; and on public health are discussed. By analyzing available data it is estimated that the minimal annual costs of salt use to the snowbelt states approximates $3 billion, distributed as follows: Surface and groundwater water supplies with the potential for irreversible public health damage to the hypertension-sensitive segment of the population - $150 million; vegetation - $50 million; highways and bridges - $500 million; vehicles - $2000 million; underground power transmission lines - $10 million; and salt purchases and application - $200 million. The damage cost is almost 15 times the annual national budget for the purchase and application of road salt, and about six times the entire annual national budget for snow and ice removal. It is recommended that the level of salting be reduced by an amount determined by local conditions and that greater emphasis should be placed on plowing and sanding snow removal methods. Educational programs should be instituted to alert the public to the extent of salt damage and greater emphasis should be placed on driver training under winter conditions.


Groundwater and surface water chemistry in southeastern Michigan is undergoing change as a result of the long-term, land use practice of using sodium chloride (road salt) as a road deicing agent. Groundwater chemistry in the vicinity of major roads and highways is evolving from a Ca-HCO3 type water to a Na-Cl type water. Persistent plumes of Cl-rich groundwater have been detected in a series of groundwater monitoring wells located nearly one kilometer north of Michigan Avenue, a major east-west trending highway located in Dearborn, Michigan. Although road salt is only applied as a road deicing agent during the winter months, the long-term impact of this practice is a change in surface water quality as this plume of Cl-rich groundwater discharges to the Rouge River, an important tributary to the Detroit River and a known source of organic and inorganic contaminants to the lower Great Lakes. The analysis of groundwater collected from monitoring wells along the north side of the Rouge River, which parallels Michigan Ave. and along the south side of Michigan Ave. (upgradient wells) show normal Ca-HCO3 type water. These results suggest that Michigan Ave. is the source of the chloride contamination. The spatial variability of the chloride concentrations, for example, higher levels closer to the highway, supports this conclusion.


Soil from an infiltration trench for highway runoff was leached in columns alternately with NaCl and de-ionised water to simulate the runoff of de-icing salt into the trench followed by snowmelt or rainwater. Simultaneously, two columns with the same soil were leached with de-ionised water throughout the experiment. In addition, the groundwater below the infiltration trench was sampled on some occasions. The column leachate and groundwater were split into two sub samples, one was filtered through a 0.45 mu m filter; both were analysed for Pb, Cd, Zn, Fe and total organic carbon (TOC). The column experiment showed clearly that an extensive mobilisation of Pb occurred in low
electrolyte water leaching following NaCl leaching. The high Pb concentration coincided with peaks in Fe and TOC concentrations and implied colloid-assisted transport. Conversely, Cd and Zn concentrations were raised in the NaCl leachate and a high correlation with Cl showed that Cl complexes are important for the mobilisation, although a pH effect and ionic exchange cannot be excluded. Only 0.15% and 0.06% of the total amount of Pb was leached from the columns leached with alternating NaCl and deionised water confirming the usual hypotheses about the high immobility of Pb in soils. However, on one occasion when the ionic strength and pH was the lowest measured the concentration of Pb in groundwater sampled from 2.5 m depth was 27 μg/L in the dissolved phase (0.45 μm). These Pb concentrations are almost 3 and 8 times above the Swedish limit for drinking water quality. Accordingly, in spite of the immobility of Pb the accumulation in roadside soils is so large that groundwater quality is threatened. In conclusion, the study suggests that roadside soils impacted by NaCl from de-icing operations contribute Pb to groundwater by colloid-assisted transport.


Over 317,000 tonnes of road salt (NaCl) are applied annually for road deicing in the Twin Cities Metropolitan Area (TCMA) of Minnesota. Although road salt is applied to increase driving safety, this practice influences environmental water quality. Thirteen lakes in the TCMA were studied over 46 months to determine if and how they respond to the seasonal applications of road salt. Sodium and chloride concentrations in these lakes were 10 and 25 times higher, respectively, than in other non-urban lakes in the region. Seasonal salinity/chloride cycles in the lakes were correlated with road salt applications: High concentrations in the winter and spring, especially near the bottom of the lakes, were followed by lower concentrations in the summer and fall due to flushing of the lakes by rainfall runoff. The seasonal salt storage/flushing rates for individual lakes were derived from volume-weighted average chloride concentration time series. The rate ranged from 9 to 55% of a lake’s minimum salt content. In some of the lakes studied salt concentrations were high enough to stop spring turnover preventing oxygen from reaching the benthic sediments. Concentrations above the sediments were also high enough to induce convective mixing of the saline water into the sediment pore water. A regional analysis of historical water quality records of 38 lakes in the TCMA showed increases in lake salinity from 1984 to 2005 that were highly correlated with the amount of rock salt purchased by the State of Minnesota. Chloride concentrations in individual lakes were positively correlated with the percent of impervious surfaces in the watershed and inversely with lake volume. Taken together, the results show a continuing degradation of the water quality of urban lakes due to application of NaCl in their watersheds.


The component of snowmelt pollutant washoff due to sand and salt application to roadways in Minnesota is simulated. Laboratory methods are used to extract various pollutants from sand-salt mixtures commonly used in the Minneapolis-St. Paul Metropolitan Area of Minnesota for keeping winter road conditions safe. Values derived in the laboratory are compared with actual snowmelt runoff values to estimate the contribution of materials application. High concentrations of solids, phosphorus, lead and zinc in snowmelt from road surfaces are due in part to sand and salt spread to improve winter driving conditions. The source of sand and salt appears to be influential in determining the pollutant levels. Judicious use and careful application of materials can
reduce the increment of pollution due to anti-skid sand and salt applied to road surfaces. The amount of salt in the mixture is positively correlated with the total Pb in the extracted sample solutes.


Concentrations of Na, Cl, and total cyanide (simple + complex forms of cyanide) in surface waters adjacent to uncovered, outdoor sand-salt storage facilities were monitored for the calendar year 1988. Runoff of deicing salt from these unprotected sand-salt piles resulted in Cl concentrations up to 13,500 mg/L in surrounding surface waters, indicating substantial leaching of road salt from sand/salt storage lots. The use of sodium hexacyanoferrate(II) as an anti-caking agent in road salt resulted in up to 200 microg/L total cyanide (CN) in surface waters adjacent to sand-salt piles. Concentrations of Na and Cl were highest during the summer months whereas the concentrations of total CN were highest during the autumn months. The observed concentrations of CN were less than the calculated maximum concentrations based on total CN content in pure road salt, indicating that sodium hexacyanoferrate(II) was being adsorbed during overland flow onto soils and/or sediments of the wetlands. A laboratory adsorption study using five soils and a road salt solution showed that the soils adsorbed from 25 to 83% of the sodium hexacyanoferrate(II) present in the soil-road salt suspensions. The percentage of sodium hexacyanoferrate(II) adsorbed on soils increased with decreasing soil pH.


The chloride and lead concentrations of snow and runoff in Ottawa were determined in order to assess whether snow melting and snow disposal practices were adversely affecting the water of local rivers. The use of sodium chloride for road deicing was shown to increase chloride levels substantially in area rivers. A portion of the lead associated with the burning of leaded gasolines could be traced in the rivers. A considerable reduction of lead input to the rivers could be accomplished by maintaining snow disposal sites away from watercourses and flood plains.


The Illinois River is one of the main tributaries of the upper Mississippi River, draining a watershed of about 78,000 km². The water quality of the Illinois River is heavily influenced by urban activities in its headwaters (particularly in the Chicago area), including road-salt affected runoff and groundwater discharge, and discharge of treated wastewater (TWW) directly into the river. Both TWW and road salt have led to increased levels of Cl⁻ in the river which can be harmful to aquatic biota. In order to examine the fate of TWW and road salt runoff in the Illinois River basin, samples were collected from the Illinois River and selected tributaries from Chicago to its confluence with the Mississippi River over a 2 year period. Samples of TWW, road salt runoff, precipitation, groundwater and tile drain water were also collected. Chloride concentrations in the Illinois River ranged from 40 to 488 mg/L. Chloride concentrations in river water spiked during the late winter and early spring as result of road salt runoff, primarily in the Chicago region. A large component of Cl⁻ in the Illinois River throughout the year was attributed to TWW from the Chicago area. Agricultural activities, which dominate land use in the watershed downstream from Chicago, imparted little Cl⁻ to the river resulting
in dilution of road salt and TWW. During periods of low flow, elevated Cl- levels were detected all the way to the confluence with the Mississippi River, demonstrating the role of TWW from Chicago in affecting Illinois River water quality when there is minimal dilution downstream. Chloride concentrations in the Illinois River have also been increasing with time. The annual median concentration at Peoria increased from about 20 mg/L in 1946 to near 100 mg/L in 2005, and concentrations have increased throughout the year, suggesting increased concentrations in groundwater. While median Cl-concentrations are well below EPA's secondary standard for drinking water (250 mg/L), periodic spikes (maximum measured in 2003 was 904 mg/L) may be harmful to freshwater biota.

A diatom-based transfer function was used to reconstruct water chemistry before European settlement in 55 Minnesota lakes. The lakes span three natural ecoregions, which differ in their history of land use, as well as in surficial geology, climate, and vegetation. Postsettlement trends were compared with water chemistry change reconstructed from two presettlement core sections (circa 1750 and 1800) as a measure of natural variability. Presettlement water quality changes were generally small and nondirectional in all three ecoregions. In contrast, half of the urban lakes showed a statistically significant increase in chloride, whereas 30% of urban and 30% of agricultural region lakes record a statistically significant increase in total phosphorus between 1800 and the present. These changes, which are attributed to road salt and nutrient runoff, are strongly correlated with the percentage of watershed area that is developed (residential or urban) in the case of chloride increases and the percentage of developed (metropolitan areas) or agricultural (agricultural areas) land in the case of nutrient increases. Water quality has changed little since 1800 for lakes in the forested regions of northeastern Minnesota. The few changes that are seen in this region are likely related to natural variations in climate or catchment soils.


A snow-melting experiment was performed to study the effects of road salt on the melting of urban snow from a snow windrow (pile) along a road in central Lulea, Sweden. Two snow piles were formed in the laboratory, with and without road salt added, and melted under similar conditions. All meltwater was collected and analyzed. The purpose of the experiment was to study the influence of the use of de-icing salt on meltwater quality and the release of pollutants from urban snow. The study indicated that the use of road salt may increase the dissolved metal phase in the urban snow meltwater. Also, the salt seems to have the largest effect at the beginning of the melting period when chloride is leaving the snow pile. Of total chloride, 90% was transported with the first 20% of the meltwater. Concentrations of the particulate-bound metals showed a fairly constant rate of release at the start of melt, but increased rapidly towards the end of the melting period, and this was more pronounced in the case of snow containing high chloride concentrations. Overall, a larger transport of solids was found for the pile with salt due to faster melting. Significantly larger masses of suspended solids and two heavy metals (Cu and Zn) were released with the meltwater from the pile with salt in
comparison with the no-salt pile. The rest of the suspended solids and heavy metals stayed in the solid residue remaining at the end of the experiment.


Analysis of variations in major ion chemistry in the Mill River watershed reveals the importance of anthropogenic activities in controlling streamwater chemistry. Average concentrations of $\text{NO}_3^-$ and $\text{SO}_4^{2-}$ show a positive correlation with percent catchment area altered by human land uses, and concentrations of $\text{Cl}^-$ increase with road density. Water removal from municipal reservoirs increases the downstream concentration of $\text{NO}_3^-$ and $\text{SO}_4^{2-}$ over that predicted by land use changes, showing that removal of high quality upstream water concentrates pollutants downstream. In salt-impacted streams, $\text{Cl}^-$ exceeds Na$^+$ by 10-15% due to cation exchange reactions that bind Na$^+$ to soil. The net effect of nonpoint source pollution is to elevate ANC in the most developed areas, which impacts the natural acidity of a large swamp. The sum of base cations ($C_B$) exceeds ANC for all samples. Plotting $C_B$ against ANC and subtracting $\text{Cl}^-$ quantifies the impact of road salt from the impact of the addition of strong acids.


De-icing salts in stream discharge from seven urban stream and suburban sub-basins were examined in a study of water quality in wetlands in central Connecticut. The proportions of sodium and potassium ions in runoff remained constant despite changes in concentrations during the snow-free season. In the snow season, concentrations of sodium ion increase by a factor of 3 or more, and a linear correlation remains, although more weakly. Why the proportions of sodium and potassium ion concentrations should tend to remain constant is not demonstrated. Linear correlations in urban runoff may require large de-icing salt inputs of sodium ions and small biological outputs of potassium ions, i.e. the ascendancy of pavement over the processes of nature. The linear regression of sodium and potassium may be the method of the future for estimating the levels of road salt in runoff. Sodium is also more important in soil, vegetation, human health than the chloride anion traditionally studied.


Runoff of road salt from an interstate highway in New Hampshire has led to a contamination of a lake and a stream that flows into the lake, in spite of the construction of a diversion berm to divert road salt runoff out of the lake drainage basin. Chloride concentration in the stream has increased by over an order of magnitude during the 23 yr since the highway was opened, and chloride concentration in the lake has tripled. Road salt moves to the lake primarily via the contaminated stream, which provides 53% of all the chloride to the lake and only 3% of the total streamflow to the lake. The stream receives discharge of salty water from leakage through the diversion berm. Uncontaminated ground water dilutes the stream downstream of the berm.

Declines in Ca and Mg in low ANC lakes recovering from acidic deposition are widespread across the northern hemisphere. We report overall increases between 1984 and 2004 in the concentrations of Ca + Mg and Cl in lakes representing the statistical population of nearly 4000 low ANC lakes in the northeast U.S. Increases in Cl occurred in nearly all lakes in urbanized southern New England, but only 18% of lakes in more remote Maine had Cl increases. This spatial pattern implicates road salt application as the major source of the increased Cl salts. Among the 48% of the lake population classified as salt-affected, the median changes in Cl (+133 meq/L) and Ca + Mg (+47 meq/L) were large and positive in direction over the 20 years. However, in the unaffected lakes, Cl remained stable and Ca + Mg decreased (-3 meq/L), consistent with reported long-term trends in base cations of acid-sensitive lakes. This discrepancy between the Cl groups suggests that changes in ion exchange processes in salt-affected watersheds have altered the geochemical cycling of Ca and Mg. One policy-relevant implication is that waters influenced by Cl salts complicate regional assessments of surface water recovery from "acid rain" related to the passage of the Clean Air Act.

Runge, I., R. M. Wright, and D. W. Urish. 1989. Modeling Sodium and Chloride in Surface Streams During Base Flows, *Journal of Environmental Engineering (ASCE) JOEEDR Vol.115*. Sodium and chloride contaminants of shallow groundwater can be frequently attributed to three major sources: (1) individual sewage disposal systems (ISDS); (2) road salt application during winter deicing activities; and/or (3) road salt storage. Effluent streams in a large reservoir watershed were sampled during baseflow conditions. Sodium and chloride concentrations were regressed against different land use types including roadway, residential commercial, industrial, agricultural, and forest areas. Results indicate that roadway areas are the largest single influence of sodium and chloride concentrations. Data from other watersheds are compared to the developed relationships and agreement is favorable. Additionally, a mass balance is performed and indicates that, typically, roadway deicing activity in the test watershed can potentially introduce far greater amounts of sodium and chloride in the local groundwater than the next greatest influence, residential septic systems.

Scott, W. S. 1979. Road De-Icing Salts in an Urban Stream and Flood Control Reservoir. *Water Resources Bulletin*. 15:1733-1742. High concentrations of chloride and sodium were found in the bottom layers of a new flood control reservoir at the beginning of winter thaw periods. The reservoir had a number of significant downstream impacts. After short thaw periods, discharge from the bottom of the reservoir tended to cause higher salt concentrations downstream in comparison with upstream sites. During long thaw periods or when large quantities of rain fell, downstream salt concentrations were considerably less than upstream values. Average chloride and sodium content of soil at the bottom of the reservoir more than doubled as a result of impounding runoff waters for one winter.

Scott, W. S. 1980. Road Salt Movement into Two Toronto Streams, *Journal of the Environmental Engineering Division, American Society of Civil Engineers*. 106:547-560. The temporal and spatial pattern of movement of deicing salts from road surfaces to stream channels was investigated in two Metropolitan Toronto stream systems. In the early stages of thaw periods, large increases in the early stages of thaw periods, large increases in stream chloride occurred immediately downstream from road crossing points. As the thaws continued and more heat accumulated, chloride concentrations decreased; and during the latter stages of the thaws, concentration was more uniform throughout the stream as the effect of dilution increased. These general patterns occurred
in both urban and rural areas, but the urban areas were characterized by a more rapid and complete removal of salt, while in rural areas, the accumulation of snow and ice in roadside ditches may take some time to melt during thaw periods creating a time lag in the movement of deicing salts to watercourses.


Factors affecting the input of deicing salts into streams were studied in the Black Creek and Don River, Toronto, Ontario. Salt inputs were significantly correlated with: (1) the length and type of road drainage into the stream, (2) the amount of salt applied prior to thaw periods, and (3) the road drainage pattern and topography. Salt levels and duration in the stream were affected by: (1) discharge of the receiving stream, and (2) degree of urbanization. At the point source inputs (road crossings) salt inputs were related to: (1) the rate of rise of temperature at the start of a thaw, (2) duration of temperature above freezing, (3) amount of salt applied prior to the thaw, and (4) amount of rainfall during the thaw. The most important independent variable for explaining salt input load was heat accumulated during a thaw. For a given thaw chloride concentrations varied in a similar manner at points in each study area. However, the Black Creek had much higher salt concentrations and much lower loads than the Don River.


Road salt runoff is a significant environmental issue in the Midwest and often contributes to changes in surface water chemistry that impact local flora and fauna. A study was conducted to observe this variation in hydrochemistry along the flow path of Tinkers Creek, the largest tributary of the Cuyahoga River in northeast Ohio. Its headwaters begin near Herrick Fen, a nearly pristine fen wetland home to a wide variety of plants and animals. Of particular interest are the many species of ostracodes, microscopic crustaceans with bivalved calcite shells. Ostracodes are indicators of groundwater-surface water interactions, as their species distributions are heavily dependent upon the hydrologic characteristics of their habitats. Within the fen several distinct microhabitats were observed in sites marked by the occurrence of groundwater recharge, discharge, or a combination of the two. Ostracode assemblages were highly diverse in the fen, and sodium chloride and nitrate levels were low, as expected for an unpolluted freshwater ecosystem. In areas of perennial groundwater discharge, water temperatures were generally cool at the surface (11 degrees C) and species such as Cavernocypris wardi, Cypridopsis okeechobei, and Microdarwinula sp. A were present. In locations where groundwater seepage was occurring along with surface water recharge, the temperature of the surface water varied depending upon the air temperature. Species assemblages included Candonia compressa, Darwinula stevensoni, Cypridopsis vidua, Physocypris globula, and Scottia browniana. At the headwaters of Tinkers Creek, surface water temperatures again mimicked the air temperatures, and ostracodes such as Physocypris globula, Cypridopsis vidua, and Cypria opthalmica were found. As Tinkers Creek was sampled along its flow path downstream to its eventual discharge into the Cuyahoga River, increased sodium chloride and nitrate levels were observed. These hydrochemical changes at the sampling locations were accompanied by changes in the ostracode species assemblages and reductions in their species richness. Ilyocypris bradyi, Physocypris globula, Candonia elliptica, Cypria opthalmica, and Heterocypris sp. (juvenile) were the
ostracodes observed farther downstream, although most sites were predominantly inhabited by *I. bradyi*.


Soil and water samples were collected at two roadside lakes and a control site to test the hypothesis that the dispersal of road salt depends on the amount of rain and runoff from snow melt. Sampling sites were evenly divided with respect to four factors: shallow/deeper water, short/moderate distance from road to lake, major/minor road, and quiet/moving water. At each lake, soil samples were taken at roadside, 8m. from roadside and at lakeside; water was drawn near the shore. Soil samples were leached with distilled water; a conductivity meter measured salinity of leachates and of water samples. Temperature, precipitation and salting journals were kept. The data show that with snow melt or light rainfall, the salt was transported through the soil and eventually into the water. With very heavy rain, transport was direct across the soil surface directly into the lake. In different terrains the transport occurred at different speeds. All but the shallowest sites returned to control levels; salinity remained high away from the roadside 4 months later, indicating incomplete transport through the soil. At the site with no curb, salinity, both soil and water, was 4 to 10 times the levels at other sites. The lack of a curb at this site allows salt to be spread directly on the soil and dumped directly into the water.


At Fever Brook, a 1260-ha forested basin in central Massachusetts, highway deicing salt application increased the solute flux in streamflow by 120% above background flux (equivalent basis) during a 2-yr period. Attempts to isolate the nonsalt component of stream solute fluxes have commonly subtracted salt contributions based on the net Cl flux (Cl output in streamflow minus Cl input in precipitation). In these studies, any net Na flux in excess of the amount needed to balance the net Cl flux has been attributed to weathering. At Fever Brook, however, the net output of Na was less than the net output of Cl, suggesting a loss of Na within the basin. The Na sink was inferred to be cation exchange of Na for Ca and Mg in the soil. A method was developed to quantify the exchange based on a Na budget, which included an independent estimate of the Na flux from weathering. The amount of exchange was apportioned to Ca and Mg based on their relative concentrations in the stream. The background fluxes of Ca and Mg (i.e., those that would occur in the absence of deicing salts) were calculated by subtracting the amounts from ion exchange plus the much smaller direct contributions in deicing salts from the observed fluxes. Ion exchange and direct salt contributions increased the net output fluxes of Ca and Mg, each by 44% above background. In basins that receive deicing salts, failure to account for cation exchange thus may result in an underestimate of the flux of Na from weathering and overestimates of the fluxes of Ca and Mg from weathering.


The use of salt for snow and ice control on northern streets and highways has grown rapidly since the 1940’s. In the winter of 1964-65, the city of Milwaukee, Wisconsin, used 33,000 tons of sodium chloride and 200 tons of calcium chloride. In the same
winter, the Wisconsin highway department used 160,000 tons of sodium chloride, or 15.8 tons per mile of highway. The chlorides, being highly soluble, are carried by runoff water to lakes and streams. The question arises as to possible damage to the aquatic and terrestrial environment. Environmental effects appear to be localized near large urban centers and along heavily used freeway routes. Diamond Lake, in Hennepin County, Wisconsin, which receives the discharge of a major storm sewer, now has a chloride content of 2,270 ppm, equivalent of 3,780 ppm sodium chloride. To place these values in the perspective of fish tolerance, bluegills will tolerate 10,000 ppm, sodium chloride. Rainbow trout sustained 20% mortality at 12,000 ppm. A build-up of sodium chloride can cause complete soil sterility. Studies show a substantial build-up in chloride content of domestic wells located adjacent to main highway systems. Chloride levels exceeding the potable water supply standard of 250 ppm have been found in many states during recent years as a result of road salt application.


Loading trends and sources of Cl- in the South Fork of the Shenandoah River, Virginia were analyzed for the period 1929-1982. Cl- has increased from approximately 2 mg/L (2776 tons/yr) to over 10 mg/L (14,256 tons/yr). Natural Cl- is estimated to be 1.01 mg/L (1388 tons/yr) with precipitation providing 0.99 mg/L and rocks 0.02 mg/L. From 1929 to 1949 Cl- concentration were relatively constant and independent of discharge, indicative of natural or relatively uncontaminated streams. Since 1952 Cl- concentrations increased exponentially as river discharges decreased, indicating polluted streams. Since 1965 anthropogenic Cl- loading at 12,868 tons/year has remained relatively constant. Four major sources contribute 92.2 % (11,871 tons/yr) of the anthropogenic Cl-: (1) deicing salts--4149 tons/yr, (2) domestic sewage--3015 tons/yr, (3) livestock and poultry wastes--2458 tons/yr, and (4) commercial fertilizers---2249 tons/yr.


The chemical mass balance approach for the chemically conservative solute, chloride, is especially useful to differentiate between natural and anthropogenic source of solutes to river waters. Monthly data from 1974-1979 on river discharge and chloride concentrations were obtained at 16 sites along the Mississippi River and major tributaries for the data base of NASQAN and from annual data reports of the USGS. Chloride deposition from precipitation in the Mississippi river watershed generally reflects the proximity of a given location to the Gulf Coast, where precipitation is greater and contains higher concentrations of sea salt. Mass budgets for chloride were estimated for the Mississippi River from headwaters to near the mouth to determine the magnitudes of natural and anthropogenic sources. Annual chloride input from precipitation ranged from about 200 kg sq mi/yr at Royalton, Minnesota, to about 350 kg sq mi/yr at Vicksburg, Mississippi. Mass export ranged from about 900 kg sq mi/yr at Royalton to about 8000 kg sq mi/yr at Vicksburg. As much as 80% of the residual, the difference between input and export, probably is contributed by anthropogenic sources. Semi-logarithmic scatterplots of monthly total discharge against chloride concentration show that, during early spring, chloride elevations in the Mississippi River and the Ohio River are elevated, possibly because of flushing of road salt and leaching of chloride from the accumulated snowpack. Scatterplots of chloride versus discharge for sites on the Mississippi River show great scatter, without the definition of discrete straightline segments. This suggests numerous sources of anthropogenic chloride unrelated to season and the effects of hydrologic control of river discharge through reservoirs and dams.
Scaled chrysophytes and planktonic diatoms are used to infer changes in lake water pH, specific conductivity, trophic score, and total nitrogen in 23 Connecticut waterbodies over the last 100 yr, and the changes are correlated with quantified changes in land use in the surrounding watersheds. In general, there was good agreement between the changes inferred from both organismal groups in this suite of lakes. Significant correlations were observed between chemical conditions inferred from organisms in surface sediments and present-day land uses, especially the percentages of the watersheds that are forest or residential land cover types. Approximately 20% of the water-bodies have significantly increased in pH since 1890, and none of the lakes have significantly declined in pH despite the fact that this region receives significant amounts of acidic deposition. These findings support previous work, indicating that the pH of Connecticut lakes has not declined over the recent past. One fourth of the lakes have significantly increased in specific conductivity, especially those situated in watersheds that have become highly residential in nature. Inferred specific conductivity has more than doubled in six of the lakes during the last century. Six of the lakes have become significantly more eutrophic, while only one lake has become more oligotrophic since 1890. The majority of the lakes situated in watersheds that have remained over similar to 80% forested have not significantly changed, whereas those that have become over similar to 25% residential have experienced the greatest amount of change. The potential influences of watershed-based alkalinity generation, winter road salt use, and implications of these findings in lake management are discussed.


Little Round Lake occupies a small, deep, cup-shaped basin in southeastern Ontario. The lake is presently oligo-mesotrophic and is chemically stratified with a distinct chemocline near the 11 m level. The watershed has been subjected to moderate cultural disturbances over the last century; first by loggers and the building of a railroad adjacent to the lake, and later by the construction of two highways. Pollen analyses were used to identify past changes in terrestrial vegetation, while limnological conditions were interpreted on the basis of diatom and chrysophyte microfossils. Contemporaneous with the arrival of European settlers (ca. A.D. 1850), the predisturbance assemblage of oligotrophic Cyclotella diatoms was replaced by Synedra spp., which then succeeded to a eutrophic flora dominated by Stephanodiscus hantzschii. Synuracean algae were almost completely excluded. Both the diatom and chrysophyte microfossils recorded a marked return to oligotrophy over the last 30 years. Stephanodiscus hantzschii was reduced to trace levels and the diatom assemblage was dominated by oligotrophic taxa. Synuracean scales were common. This shift may be related to the cultural enhancement of meromixis by the seepage of road salt from the two adjacent highways and a salt storage shed in the drainage basin. Although an increase in meromictic stability appears to have greatly reduced algal productivity, the species composition in the surface sediments suggests that the lake is still slightly more eutrophic than it was prior to man’s arrival.

Chloride based deicers, commonly referred to as road salt are the most common substances used for the purpose of roadway ice and snow removal. Upon application, road salt readily dissolves and dissociates, causing increased concentrations of the respective ions in nearby soils, surface water and groundwater. Of the ions present in road salt, chloride is the most conservative and is the focus of this study. For this study, we use a robust, four year dataset consisting of continuous (15 minute interval) specific conductance and discharge records collected by the USGS for the Saugus River site from 2003 to 2007. Specific conductance values were empirically calibrated to represent chloride concentrations which provided ways to indirectly monitor chloride variations in the stream channel. The real time chloride concentration dataset, coupled with the real time stream flow rates can be combined to calculate total dissolved chloride loads discharging from the Saugus River. The dissolved chloride loads exhibit seasonal fluctuations in flow rate and dissolved chloride load. During the winter months of December and January, when road salt use is at its peak, the Saugus River averaged a flow rate of 55 CFS transporting an average of 790 kg of chloride per hour (a total of 1,280 tons for 2 months). In contrast, during the summer months of July and August the Saugus River averaged a flow rate of 17 CFS transporting an average of 228 kg of chloride per hour (a total of 340 tons for the 2 month period). From hydrograph separation of precipitation events, groundwater base flow discharge contributes the bulk of the dissolved chloride load in the summer months. We present an analysis of the dissolved chloride load distribution during precipitation events in the summer and winter seasons. The results of analysis on Cl transport mechanisms in the environment show that the migration pathways of salt are complex involving at different times and in different proportions aquifer flow, baseflow, interflow, overland flow, evaporation, and transpiration processes.

Thunqvist, E. 2004. Regional increase of mean chloride concentration in water due to the application of deicing salt. Sci. Total Environ., 325:29-37. Establishing a Framework for Community Action in the Field of Water Policy, states that it is necessary to consider human activities within a river basin in order to prevent and reduce the spreading of pollutants and to achieve good water status. This paper shows a simple method to estimate the environmental pressure from the deicing of roads as steady state chloride concentration in water. The data processed are presented using GIS. The result showed that the contribution of deicing salt is of importance for the chloride concentration on a regional scale. The increase in chloride concentration is also compared to the background concentration and other sources of chloride within the river basin. Road salt applied by the Swedish National Road Administration (SNRA) accounts for more than half of the total chloride load for the river basin investigated. The method presented may easily be generalised to a national scale for monitoring the environmental effects of deicing salt application.

US Geological Survey. 2009. Chloride in Groundwater and Surface Water in Areas Underlain by the Glacial Aquifer System, Northern United States, National Water Quality Assessment Program, Scientific Investigations Report 2009-5086. A study of chloride in groundwater and surface water was conducted for the glacial aquifer system of the northern United States in forested, agricultural, and urban areas by analyzing data collected for the National Water-Quality Assessment Program from 1991 to 2004. Chloride loads and yields were determined at 95 surface-water-monitoring stations in basins dominated by forested, agricultural, or urban land. Annual chloride yield was largest in the urban basins (median of 88 tons per square mile) and smallest in the forested basins (median of 6.4 tons per square mile). The median chloride yield in the
agricultural basins was 15.4 tons per square mile. Multiple linear regression analyses showed that the density of highways (roads in U.S. highway system), the number of major wastewater discharges in the basin, potential evapotranspiration, and urban minus agricultural land area were significant factors in describing the range of average annual chloride yields. Upward trends in chloride loads were apparent in several urban basins for which additional long-term data were available. Increases in chloride loads over time may be related to a variety of factors, including increases in road area and consequent deicing, increases in wastewater and septic-system discharges, recycling of chloride from drinking water, and leachate from landfills and salt storage areas.


This overview of research findings presented at the conference on urban drainage and highway runoff in cold climates starts with generation of urban runoff and snowmelt, followed by snowmelt and winter runoff quality, best management practices for urban snowmelt and winter runoff, and snow management in urban areas. Research on the urban hydrological cycle is lagging behind the needs in this field, particularly in terms of data availability. The current studies of winter urban runoff quality focus on road salts in the urban environment and their environmental effects. The needs for better source controls in salt applications, improved management of chloride-laden runoff, and selective adoption of environmentally safer alternative de-icers were reported. Adaptation of the conventional stormwater best management practices (BMPs) for winter operation remains a challenge. The first step in refining the existing BMPs for winter operation is to advance the understanding of their operation, as reported for some cases at the conference. Finally, snow management in urban areas may require local storage of fresh (unpolluted) snow and disposal of more polluted snow at central snow disposal sites.


Among the costs imposed by the use of deicing salt is the elevation of sodium levels in drinking water. Road salting in New York State is found to elevate the levels of sodium in the drinking water supply. The possibility of a link between road salting, higher sodium levels in drinking water, and deaths due to hypertension naturally arises. Cross section regression and econometric estimates of hypertensive deaths across 69 communities in New York State indicate a positive but statistically insignificant correlation between sodium levels in drinking water and hypertensive related deaths. The mean sodium level in these samples is 8.8 mg/l (s.d. = 15.2), much lower than the 20 mg/l thought to pose a danger to human health. Moreover, there was no statistically significant relationship when hypertensive deaths were separated into cases with and without heart disease. However, data limitations suggest that it may be premature to issue a clean bill of health to road salting. In correlating road salting with the measured level of sodium in drinking water supplies, there is a statistically positive effect detected.


Distribution coefficients (K_d) were used to estimate the most important geochemical phases within the suspended particulate matter (SPM) pool for sorption of Cd, Cu and Zn. Given that pH effects were expected to be minimal, as the Don is a well buffered system,
the possible influence of secondary environmental variables [temperature, dissolved organic carbon (DOC), dissolved Ca\(^{2+}\) and NaCl] on trace metal partitioning between SPM and the dissolved phase was evaluated using a series of multiple linear regressions for total (K\(_d\)T) as well as the phase specific (K\(_d\)L leachable phase; K\(_d\)R reducible phase; and K\(_d\)O oxidizable phase) distribution coefficient estimates. The three metals varied in their sorptions patterns. Cd and Zn showed the same relative affinities for three SPM pools (leachable = reducible > oxidizable), while Cu affinities ranked oxidizable = leachable > reducible. Secondary environmental factors were identified as more important influences on trace metal partitioning than pH. Temperature and NaCl (from road salt runoff) were found to be key environmental variables influencing trace metal partitioning. A decrease in water temperature caused decreases in the accumulation of Cd, Cu and Zn in the particulate pool. Increasing NaCl concentrations decreased the concentrations of Cd and Zn associated with the particulate leachable phase and the Cd, Zn and Cu content in the oxidizable SPM phase. These results suggest that in running waters during winter months, or even during summer months in the hypolimnia of sufficiently deep lakes, a relatively higher proportion of these metals remains in the dissolved and potentially more bioavailable pool.


During the relatively mild winter of 1972-1973 20,260 metric tons of NaCl and 40 metric tons of CaCl\(_2\) were spread on roads within the salt creek basin of the Chicago metropolitan area. Over 600 water samples were collected from 11 creek sites within the basin during the salting season. Chloride concentrations in the water varied from 35 to 1530 mg/l during the sampling period. Road salt chloride content of the water at any time is dependent on (1) temperature and colligative properties of NaCl, (2) duration of precipitation events, and (3) dilution capacity of the stream. Models were presented for three subsections of the basin based on the relationship between chloride concentration and discharge of the creek during nonsalting periods. A fourth subsection could not be modeled because of insufficient data. Monthly chloride budgets for all four subsections from November 1 through April 30 show that between 55 and 72% of the road salt chloride was removed by the creek from the various subsections. Changes in the percentage of chloride removed correlated well with the following indicators of the degree of urbanization: (1) percentage of area as streets, (2) highway density, (3) population density, and (4) road salt application per unit area.


This study evaluates the effects of population growth on water quality in a mountain watershed using multivariate statistical techniques. Extensive development in Turkey Creek Basin (TCB), Jefferson County, Colorado, accommodates the need for residential living in the mountains near the Denver metropolitan area. Population in TCB has doubled in the last 25 years and is projected to double again in the next 20 years. Two large water-quality datasets, collected by the U.S. Geological Survey and the Colorado Geological Survey, are supplemented with irregular water sampling over the last thirty years and continued monitoring by the Colorado School of Mines research team. The compilation of data into a relational database includes approximately 450 sampling sites.
in the 47 mi² basin with approximately 15,000 results including field parameters, major ions, nutrients, and trace elements. Hierarchical cluster analysis (HCA) and principal component analysis (PCA) use chemical and physical properties to objectively partition the water-chemistry samples into hydrochemical facies with specific chemical characteristics. These hydrochemical facies relate to local and intermediate flow paths from a conceptual ground-water flow model of the basin. In addition, the hydrochemical facies segregate impacted water samples (high Na, Cl, and NO₃) from non-impacted water samples and reveal possible sources of degradation. This technique demonstrates that the spatial and temporal variability in water chemistry occurring as population has increased over the last three decades is related to at least one anthropogenic influence. Geochemical models, using the PHREEQC code, indicate that the current water quality conditions can be reconstructed using non-impacted water, septic tank effluent, and a NaCl solution, representing road salt applications, mixed in various proportions. Using insights gained from this study, we can predict probable future impacts of growth on water quality for similar mountain watersheds.
SOIL IMPACTS


Laboratory batch incubation studies were carried out to determine the effects of aerobic and anaerobic conditions on the solubility of trace metals in soils and waters treated with the deicing salts calcium magnesium acetate (CMA) and NaCl. The concentrations of trace metals were, in general, not controlled by equilibrium reactions but rather by the relative rates of several simultaneous and sequential reactions. In three soils from CA, NJ, and MI, and water treated with CMA the production of HCO$_3^-$ from acetate decomposition initially increased the solution concentration of Pb and Zn as PbCO$_3$ and ZnCO$_3$. Eventually, supersaturation with respect to calcite occurred and the concentrations of Cu, Cd, Zn, V, and Cr decreased because of coprecipitation with the calcite. The precipitation of pyromorphite [Pb$_5$(PO$_4$)$_3$Cl] was suspected based on elevated saturation indexes for this mineral. At low redox conditions, the solubilization of Fe- and Mn-oxides increased the concentration of the trace metals that were adsorbed or coprecipitated with these phases. Supersaturation with respect to MnCO$_3$, FeCO$_3$, and VO(OH)$_2$ occurred under low redox conditions. The rate constant for acetate decomposition under anaerobic conditions was 18 times lower than the rate constant for aerobic decomposition. This suggests that if a soil received a high loading of CMA, low O$_2$ conditions could occur and CMA might leach to groundwater. There is evidence that the use of CMA could result in Pb and Zn mobilization as neutral ion pairs with carbonate.


Of several impacts of road salting on roadside soils, the potential disruption of the nitrogen cycle has been largely ignored. Therefore the fates of low-level ammonium-N and nitrate-N inputs to roadside soils impacted by salting over an extended period (decades) in the field have been studied. The use of road salts disrupts the proportional contributions of nitrate-N and ammonium-N to the mineral inorganic fraction of roadside soils. It is highly probable that the degree of salt exposure of the soil, in the longer term, controls the rates of key microbial N transformation processes, primarily by increasing soil pH. Additional influxes of ammonium-N to salt-impacted soils are rapidly nitrified therefore and, thereafter, increased leaching of nitrate-N to the local waterways occurs, which has particular relevance to the Water Framework Directive. The results reported are important when assessing the fate of inputs of ammonia to soils from atmospheric pollution.


Widespread use of sodium chloride as a deicing agent on roads poses a potential threat to nearby soils. Sodium cations in meltwater infiltrate into soils adjacent to roads and may adsorb onto clay minerals. The purpose of this study is to measure sodium using sodium adsorption ratios (SAR), a measure of the extent of sodium saturation, in sandy soils near roads in a temperate, snowy climate. The concentrations of three major cations, Na, Ca, and Mg, were also measured to calculate SAR. SAR data for soils in Grand Traverse County, Michigan were assessed by sampling at four locations which have different
salting application rates but similar soil characteristics. Sampling occurred over one winter season in September 1996, December 1996, and March 1997. SAR values increased markedly from September to December at each site, indicating deicing operations are the probable source of sodium cations to the soils. At some sites a significant decrease in SAR occurred in March due to rapid melting of surface snow, decreased salting operations, and early spring rains. Only rarely was a correlation between SAR and distance from the road or depth in the soils found for any given time period. The data indicate that soil texture is more significant in determining the adsorption of sodium than salt application rate. Low SAR values in soils throughout the sampling period indicate that sodium is at present not accumulating in roadside soils at the four sampling sites.


Migration of road salt through soils of various cation exchange capacities (CEC’s) is more rapid in soils having low CEC than those with higher CEC. Much of the yearly input of road salt occurs during the spring thaw, although an observed movement of salts occurred throughout the winter months. The greatest seasonal increase in soil leachate sodium and chloride concentrations occurred in previously unsalted soils and those of low CEC. Lateral road salt distribution in soils was primarily restricted to within the highway right-of-way, although slight fluctuations in adjacent well water salt content were observed. Soils with low cation exchange capacities have a low capacity to adsorb the sodium cation (in exchange for calcium, magnesium and potassium). Soils with a high cation exchange capacity exhibit a greater buffering effect and will, therefore, concentrate sodium (in exchange for the calcium, magnesium and potassium cations) when sodium is supplied in excessive amounts. In this way, light textured (sandy) soils with low cation exchange capacities will allow a more rapid entry of road salt to groundwater and surface water. The heavier textured (clayey) soils will buffer the groundwater and surface waters from salt pollution but will concentrate these ions in the soil.
BMPs


The characteristics of calcium magnesium acetate (CMA) as a substitute for salt as a highway deicer are discussed. Road salt is responsible for costly rusting of vehicles, bridges, and road surface retaining rods, as well as water supply contamination in the northeastern United States. CMA is the most promising among several alternative deicers that have been studied. Its main drawback remains the lack of an economical and reliable means of production. Although it is nearly 20 times as expensive as road salt, it does not harm the environment and may actually yield some benefits, including neutralizing acidified solids and waters.


A deicing alternative, calcium magnesium acetate, that is safe for the environment, less corrosive than salt, and effective has been developed. To assess the environmental impacts and effectiveness of the new deicing chemical, calcium magnesium acetate was compared to salt. Calcium magnesium acetate's movement over and through roadside soil is influenced by the same physical factors that influence salt dispersion. Calcium magnesium acetate can enhance plant growth by improving soil permeability and providing needed calcium and magnesium, which may be a valuable characteristic in areas where heavy salt use has resulted in soil compaction. The impact of calcium magnesium acetate on groundwater is negligible. Even with conservative assumptions, all applied calcium magnesium acetate flows directly into a body of water immediately adjacent to the road and all the acetate degrades at once. To determine the effects of calcium magnesium acetate on phytoplankton, water samples from 10 California lakes were incubated with 0.1, 1.0, and 10 mg/L of calcium magnesium acetate. Eight of the ten lakes showed no significant effects of the addition. Adding calcium magnesium acetate to a concrete and steel system undergoing active chloride corrosion slowed corrosion rates after 30 days and stopped corrosion after 60 days. Although calcium magnesium acetate and salt deice differently, the storage, handling and spreading characteristics of calcium magnesium acetate are comparable to those of salt. Since first becoming commercially available in the mid-1980s, calcium magnesium acetate has proven to be an alternative deicer that can provide safe winter driving without compromising the roadside environment, water supplies, or expensive highway structures.


This study evaluated the water-quality benefits of a new urban best management practice design called the multichambered treatment train (MCTT). The study consisted of collecting flow-weighted water-quality samples at influent and effluent locations for 15 consecutive storms. Device efficiencies were based on load reductions of 68 constituents. Total rainfall amounts for the 15 storms ranged from 0.45 to 3.48 cm, yielding 1.7 to 8.9 m super(3) of water treated by the device. None of these storms surcharged the unit. High reduction efficiencies were found for all particulate-associated constituents, such as total suspended solids (98%), total phosphorus (88%), and total recoverable zinc (91%). Dissolved fractions had substantial but somewhat lesser removal rates (dissolved phosphorus, 78%; dissolved zinc, 68%). Total dissolved solids, which originated from road salt storage, yielded 4 times the total suspended solids load. No appreciable shift was seen between influent and effluent particle size distributions.

Calcium magnesium acetate (CMA) is thought to be the best alternative to salt for use as a roadway deicer. The objective of this study was to determine how CMA would affect particular microbial communities and functions that occur in natural lake ecosystems. Water samples from 10 lakes in northern California were incubated with concentrations of 0.1, 1.0, and 10.0 mg/L of CMA and the response of phytoplankton evaluated by analysis of final chlorophyll concentrations. CMA appeared to have a minimal effect on natural phytoplankton in a wide variety of lakes. In 8 of the 10 lakes, no statistically significant alteration in chlorophyll biomass was observed with the concentrations of CMA used in the study. In the second set of experiments, both primary production and acetate uptake of Castle Lake phytoplankton and bacteria had no significant response to the concentrations of CMA used in the study. However, there was a significant increase in phosphorous (P) uptake in the fraction whose size was > 3.0 micrometers, along with a significant increase in chlorophyll biomass. The increase in P uptake in the Castle Lake microbial community may have been due to bacterial populations present on detrital particles. Within the scope of this investigation, CMA appeared to have minimal effects on the natural lake microbial ecosystem.


Conventional road salt has long been responsible for corrosive effects on cars and highway structures, as well as some undesirable impacts on terrestrial and aquatic ecosystems. This has resulted in investigations of a variety of alternative deicing compounds. Early studies in northern California demonstrated the formation of a salt-stabilized chemocline in Putt's Lake along Interstate 80 in the Sierra Nevada. Current studies on natural populations of algae and bacteria indicate that calcium magnesium acetate (CMA) appears to be a good alternative to sodium chloride. Bioassays of 10 northern Californian lakes were conducted in situ with various concentrations of CMA. During the summer, eight out of the 10 lakes showed no significant response in algal biomass with the CMA concentrations. Bioassays done during the late spring and early winter showed only slight deviations from these results. Temperature, prevailing weather conditions, and standing stock of microbial populations appear to be the dominant factors in determining whether or not an algal response was evident in these seasonal CMA bioassays. In a series of laboratory bioassays with natural microbial communities from Castle Lake, CMA had no significant effects on primary production or the uptake of acetate by bacteria. A significant increase in phosphorus uptake by the 'algal' fraction (> 3 mu m) in lakewater occurred at CMA concentrations of 10 ppm. This increase in P-uptake was attributed to bacteria that were associated with detrital particles in the water. At the same time we observed a significant decrease in algal biomass. Within the scope of this investigation CMA appeared to have minimal effects on phytoplankton biomass other than the observed stimulation of P-uptake which may be due to competition between the natural bacterial and algal populations.


De-icers are essential to wintertime road maintenance in Nordic countries. The use of road salts (NaCl, CaCl₂ and MgCl₂) is having significant effects on groundwater. There

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has been a growing concern of environmental effects resulting from de-icing. Regulatory bodies have tried to find de-icers which have less harmful impacts on soil and groundwater. Alternative new organic de-icers are e.g. potassium formiate, potassium acetate, and calcium magnesium acetate. Objectives: At present, the decision finding for soil and water quality assessment is mainly based on the results of chemical analyses. However, ecotoxicological characterization will provide more useful information for determining environmental effects of de-icers. Methods: Six different de-icers, NaCl, CaCl$_2$, MgCl$_2$, potassium formiate KFo, potassium acetate KAc and calcium magnesium acetate CMA were studied with different bioassays. These bioassays were two plant tests (onion Allium cepa root elongation test and duckweed Lemna growth inhibition test), an enzyme inhibition test (reverse electron transport test, RET) and a microbial test (luminescent bacteria Vibrio fischeri, BioTox test). Results and Discussion: Most of the responses of the de-icers tested were toxic to test organisms. CMA was unsuitable for RET and BioTox tests because it was not possible to analyze turbid samples with these bioassays. On the whole, organic chemicals were more toxic than the inorganic salts. According to the Lemna and Allium cepa tests KFo was the most toxic and the toxicity ranking of the de-icers was KFo>KAc>CMA>CaCl$_2$>NaCl>MgCl$_2$. The sensitivity ranking for tests in decreasing order was Lemna>Allium cepa>RET>BioTox. The plant tests proved to be relevant, easy, cost-effective and sensitive screening methods of de-icers: Lemna test was 92 times more sensitive and Allium test 70 times more sensitive than BioTox to KFo. Conclusion and Outlook: The tested de-icers had significant effects on plant growth, microbial luminescence and enzymatic activity. Toxicity could hardly be predicted from the chemical concentrations of these de-icers. In summary, these results demonstrate a need for including toxicity measurements in the evaluation of technologies used in soil treatment and illustrate the potential value of such measurements for ensuring that no or minimal environmental contamination would arise from de-icing process.


The formation of dense snowpack and ice on high volume roadways is of major concern during snow removal operations. The use of conventional snowplow blades, which normally lack the ability to deeply penetrate a snow cover of this type, results in the excessive use of chlorides, equipment, and time. This report covered both current problems encountered during snow removal operations and a new concept for the removal of a dense snowpack and ice from a pavement surface. The concept proposed using a NaCl brine solution under high velocity jet stream conditions to penetrate a snowpack. It was found that the abrasive qualities of a turbulent boundary layer around a jet stream and the drag produced by the pack in changing the momentum of the brine stream destroy or loosen the pack sufficiently to enable economical and effective plowing.


This paper describes how the runoff from roads and other paved surfaces can be attenuated and treated by a sand/gravel filter tank. It proposes a design for such a tank and gives details of tests carried out on a two-dimensional (2D) section of the tank. These tests showed that significant reductions were achieved in suspended solids, biochemical oxygen demand (BOD), chemical oxygen demand (COD) and concentrations of road salt, although there was little effect on the levels of metals. This work also shows how the hydraulic performance of such a tank can be represented by a double-reservoir model.
using both design storm events and historic rainfall data. A 2D finite difference model of the tank is also described.


Calcium magnesium acetate (CMA) has been recommended as the best alternative to road salt for roadway deicing due to its potential for large-scale production and relatively low levels of toxicity on terrestrial and aquatic organisms. All the information collected to date indicates that the CMA concentrations used to deice roads have little or no toxic effects on roadside vegetation. Preexisting heavy metals are not released from a variety of roadside soils and CMA may provide some benefits to soil structure. CMA has shown little to no toxic effects on the aquatic species that have been tested, including vertebrates and invertebrates. Algal, periphyton, and phytoplankton biomass are not increased when CMA is used. CMA is unlikely to cause treatment problems in sewage treatment plants receiving expected runoff if the chemical is used. No significant impact from CMA is expected on receiving water dissolved oxygen for most scenarios. The toxicological effects of CMA were similar to or less severe that sodium chloride in a full complement of short-term toxicity tests, leading to the conclusion that CMA has low acute mammalian toxicity and should affect workers' health no differently that salt. The negative environmental and toxicological impacts are likely to be insignificant in the vast majority of CMA applications.


During the winters of 1974-75 through 1986-87, the Massachusetts Dept. of Public Works (MDPW) applied an average of 198,000 tons of sodium chloride on Massachusetts highways during winter snow and ice control operations, at an average rate of about 16.5 tons/lane mile/winter. This salt application caused sodium levels in groundwater and water supplies near highways, in some locations, to increase significantly above the natural background level in this area of about 10 mg/L. During the period January 1982 through May 1988, the Massachusetts Dept. of Public Works received 139 complaints of salt contamination of private wells. These complaints were resolved by: (1) well replacement; (2) connection to public water supply; (3) water treatment; (4) highway drainage change; (5) use of salt substitute; and (6) complaint denied. During this period, the MDPW was provided with $2,500,000 by the state legislature, for investigation and remediation of salt contamination of water samples. In 1986, there were 73 public water supplies in Massachusetts with sodium levels above 20 mg/L. The increase, above background, of sodium in some of these water supplies was, at least partially, from the use of highway deicing salt. Complaints of salt contamination of public water supplies are resolved by: (1) reduced salting on state highways in the vicinity of the public water supply; (2) special attention given to salt handling and storage practices at maintenance facilities; (3) installation and operation of scavenger wells; (4) construction of special highway drainage systems to collect the highway runoff and carry it away from sensitive areas; and (5) complaint denied.

The increased use of deicing salts in the United States over the last 20 yrs has caused a number of environmental problems. Damage attributable to sodium and calcium chloride use includes deterioration of pavement; corrosion of steel in bridge members, highway appurtenances, and automobiles; and negative impacts on roadside vegetation, soil chemistry, aquatic ecology, wildlife, and domestic water supplies. The Federal Highway Administration (FHWA) initiated research in the mid-1970s to investigate possible alternatives to the use of conventional sodium and calcium chloride road deicers. In 1980, the Bjorksten Research Laboratories identified calcium and magnesium acetate (CMA) as a potentially suitable, noncorrosive road deicer. Subsequent research on CMA has focused on three areas: environmental acceptability; development of manufacturing technologies; and technical evaluations of CMA’s deicing ability, corrosiveness, and cost. From this simplified analysis it can be concluded that partial or complete substitution of CMA for conventional road salt in the Buffalo area would have a significant impact on POTW operation because of increased organic loadings. Increased organic loadings are likely to result in increased aeration, nutrient addition, and additional sludge handling capabilities. The severity of this impact would depend upon the extent that EMA was substituted for salt, weather conditions, and the ability of the POTW to react to transient loading surges. Such an impact must be considered to more fully assess the environmental impacts associated with CMA use as a road deicer in urban areas served by combined sewers.


This report presents the results of a study by the U.S. Geological Survey, done in cooperation with the Oregon Department of Transportation (ODOT), to evaluate the effects of the highway deicing material, calcium magnesium acetate (CMA), on the water quality of Bear Creek, in the Cascade Range of Oregon. ODOT began using CAM (an alternative deicer that has fewer adverse environmental effects than road salt) in the mid-1990s and began this study with the USGS to ensure that there were no unexpected effects on the water quality of Bear Creek. Streamflow, precipitation, dissolved oxygen, pH, specific conductance, and water temperature were measured continuously through the 1998-99 winter.

Van Loon, J. C. 1972. The snow removal controversy. Water and Pollution Control. 110:19-20. Controversy has arisen in Canada over the effects of street salting and snow dumping in lakes and rivers. For the past three years, runoff from urban streets, contamination of urban and rural water courses, runoff and solids residues in contaminated snow being dumped, airborne winter dusts and snow, and winter rains were monitored for toxic metals, chlorides, phosphorus, sodium, and calcium. The data show that: (1) phosphorus contents of snow were insignificant. (2) soluble metal contents of snow compared with that of runoff. (3) airborne dust is a major component of street snow residue. (4) the chloride value of snow was 3.1 ppm compared with 2.4 ppm for summer rain indicating that road salt is recycled into the air in winds. It is concluded that salting programs are essential for safety reasons, but salt must be used sparingly since the vast majority of salt eventually discharges into lakes and rivers regardless of disposal methods. However, as much snow as possible should be left at roadside. Heavy metal content of snow does not appear to be above that of the receiving waters. The fate of oils, greases, and toxic organics is only partially understood at the present time.

The results of a state-of-the-art review of highway deicing techniques are summarized. Information and suggestions for use in planning and initiating research are included. A literature review and a compilation of information from various organizations have promoted selections of and suggestions for promising avenues of research into alternatives to the use of chlorides. These alternatives include: (1) formamide, (2) urea, (3) tetrapotassium pyrophosphate, (4) formamide-urea-water, (5) tripotassium phosphate-formamide, (6) hydrolysates of proteinaceous waste, (7) hydrophobic coatings - such as fatty-quaternary-ammonium compounds, organo-fluorochemical compounds, organo-silicone compounds, polymers (polyethylene, plastics, aminoborane, alkali metal borohydride, alkali metals with borohydrides), (8) pavement heating, (9) mobile thermal deicing, (10) ultrasonic or vibrational techniques, and (11) various types of equipment. Undesirable characteristics are noted with the use of: ammonium acetate, ammonium nitrate, ammonium sulfate, alcohols, glycols, sodium formate, calcium formate, ammonium carbamate, and ammonium salts.
ADDITIVES


The degradation of potassium hexacyanoferrate (III) in aqueous solutions by bacteria (Pseudomonas aeruginosa and Escherichia coli) was investigated in laboratory experiments conducted in light-protected reaction vessels. A 3293 mg/L solution of potassium hexacyanoferrate (III) was prepared with sterilized water inoculated with bacteria. Within 25 days, concentrations of free cyanide increased rapidly, reaching 1460 micrograms/L. In contrast, a sterile control solution exhibited a concentration of only 15 micrograms/L within the same period. Further evidence of the significance of bacteria in the degradation of the hexacyanoferrate (III) anion was evidenced in the second experiment, where a Bacto-Nutrient Broth solution was utilized to ensure the development of large bacterial populations. In this experiment, an even higher free cyanide concentration (3952 micrograms/L) was achieved within 25 days. In terms of aquatic toxicology and in the formulation of surface water quality standards, these findings are significant, since the maximum free cyanide concentration produced in the experiments was far in excess of the 200 to 250 micrograms/L LC50 values determined for most fish species.


Most people associate the word cyanide with an extremely dangerous and fast-acting poison. However, there are several cyanide species, of varying toxicity, depending on the source to cyanide contamination. The most important cyanide compounds, as well as the most important sources of cyanide contamination in soils and groundwater are discussed. Toxicological and analytical aspects of cyanide containing compounds are briefly touched. The behaviour of cyanide compounds in soil and groundwater is governed by many interacting chemical and microbial processes. Redox conditions and pH are of importance for the leaching and degradation of iron cyanide complexes. Free cyanide is degraded under both aerobic and anaerobic conditions, while documentation of the degradability of iron cyanide complexes only exists under aerobic conditions. The risk associated to the cyanide contained in the different types of sources is evaluated. At gas work sites, where cyanide is mainly present as iron cyanide complexes, the risk for effects on humans from exposure to cyanide compounds seems to be of minor relevance.


At more than 200 sites in the Netherlands, the soil is contaminated with cyanide as a result of industrial activities. The mobility of cyanide, which mainly occurs in the form of iron cyanide complexes $[\text{Fe(CN)}_6^{3-} + \text{Fe(CN)}_6^{4-}]$, plays an important role in predicting the possible hazards for the environment and human health. Cyanide mobility was investigated by assessing data on cyanide concentrations in groundwater at contaminated sites, and by examination of three contaminated soils. High cyanide concentrations were found in the groundwater at sites with alkaline soils (pH ca. 7.5), whereas much lower concentrations were found in the groundwater with acidic soils (pH ca. 4). This agreed with the assumption that the behavior of cyanide in these contaminated soils is largely governed by the solubility of Prussian blue $[\text{Fe}_6(\text{Fe(CN)})_6]^3(s)$, which is relatively insoluble under acidic conditions. In the acidic soils, the concentrations in the soil water appeared to be close to equilibrium with Prussian blue. In alkaline soils this precipitate is
extremely soluble. The presence of this material here was possibly the result of slow dissolution kinetics. Precipitation of Prussian blue in acidic soils does not prevent


Cyanide is a highly toxic chemical which commonly occurs as an industrial contaminant in soils. Although produced in small amounts by many different organisms, it reaches toxic levels solely because of human activities. It is used in mining, metallurgical, and photographic industries, as well as in coal gasification plants. In order to improve the assessment of the bioavailability and behavior of cyanide in the environment, the speciation of dissolved cyanide was studied under pH and redox conditions relevant to soil and groundwater environments. The partition of cyanide over free cyanide (HCN aq + CN(-)) and iron cyanide complexes (or hexacyanoferrates) at thermodynamic equilibrium was calculated as a function of pH and redox potential. These calculations show that the free cyanide form will predominate at chemical equilibrium in the soil. In groundwater from sites contaminated with cyanide, however, only complexed cyanide was found, indicating that the speciation of cyanide is determined not by chemical equilibrium but by decomposition kinetics. In daylight, iron cyanide complexes appeared to decompose rapidly (ca 8%/h). In the dark, the rate of decomposition appeared to be much slower and was proportional to the fraction of hexacyanoferrate present as HFe(CN)₆³⁻ and H₂Fe(CN)₆(--). The decomposition rates of both species were determined as a function of temperature and used to model decomposition kinetics. Good predictions were made of decomposition rates under various pH and redox conditions.


Highway and road deicing operations provide traffic safety during winter driving conditions in snowbelt areas. Using large quantities of deicing chemicals causes water quality problems that need to be addressed and remediated. Two specific problems are discussed, i.e., presence of cyanides in deicing salt and decreased partitioning of metals in snowmelt resulting from high salt concentrations. Complex ferrocyanide compounds are added to salt to prevent caking. By photodecomposition, these cyanides can be broken down to free toxic cyanide compounds. For toxic metals, salt decreases partitioning between adsorbed (precipitated) and dissolved metals, resulting in an increase in dissolved metals in salt laden snowmelt and consequently increasing toxicity.


To ensure uniform spreading, sodium ferrocyanide is often added to highway de-icing salt as an anti-caking agent. Although the toxicity of ferrocyanide is low, exposure to sunlight can photodecompose the complex cyanide into simple cyanide (CN-and HCN), which is highly toxic. Four highway facilities where sand and salt are mixed and stored in uncovered piles were investigated in 1988. Exceptionally high chloride values had been reported in nearby surface waters at each site. Surface water sampling sites were selected upstream, adjacent to, and downstream from the facilities; samples were collected on a monthly basis. A well drilled into bedrock was also monitored at one location. Water samples were irradiated and analyzed for total cyanide. At the pH range found in the
sampled waters, most of the total cyanide would be in the form of simple cyanide. Elevated concentrations of sodium chloride (NaCl) and total cyanide were found in surface waters adjacent to all four facilities. Total cyanide levels exceeded guidelines set by the US EPA for the protection of wildlife (52 ppb CN⁻) and for drinking water (10 ppb CN⁻). The concentration of total cyanide in nearly all samples was below the detection limit of 10 ppb within 500 feet downstream from each site. No cyanide was detected in the well. The theoretical concentration of total cyanide for each sample was calculated using the CN⁻/Na ratio from a sample of pure road salt. At all sites the actual cyanide concentration was less than the predicted maximum concentration of cyanide. The lower than predicted levels of cyanide suggest that the cyanide is being adsorbed onto soil particles during overland flow, or is being adsorbed onto sediment in nearby bogs.


Water-soluble iron cyanide compounds are widely used as anticaking agents in road salt, which creates potential contamination of surface and groundwater with these compounds when the salt dissolves and is washed off roads in runoff. This paper presents a summary of available information on iron cyanide use in road salt and its potential effects on water quality. Also, estimates of total cyanide concentrations in snow-melt runoff from roadways are presented as simple mass-balance calculations. Although available information does not indicate a widespread problem, it also is clear that the water-quality effects of cyanide in road salt have not been examined much. Considering the large, and increasing, volume of road salt used for deicing, studies are needed to determine levels of total and free cyanide in surface and groundwater adjacent to salt storage facilities and along roads with open drainage ditches. Results could be combined with current knowledge of the fate and transport of cyanide to assess water-quality effects of iron cyanide anticaking agents used in road salt.