Rochester Committee
for Scientific Information
Rochester, NY

RCSI Bulletin 166
Environmental Effects of Deicing Salts: Introductory Bulletin

By: Lindsay K. Holmes
December 1973

THE ROCHESTER COMMITTEE FOR SCIENTIFIC INFORMATION
P. O. Box 5236, River Campus Station
Rochester, New York 14627

Bulletin #166(C)
Chemical Pollution

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Summary

The use of deicing salts on American highways has increased from a half million tons per year in 1949 to 9 million tons in the winter of 1969-70. At temperatures above -9°C (15°F) rock salt which is primarily sodium chloride (NaCl) is the most effective chemical deicer available in its price range. Calcium chloride ($CaCl_2$) increases the speed of melting at lower temperatures and it is sometimes mixed with the rock salt. In the winters of 1969-70 and 1970-71 Monroe County bought almost 2.5% of the total salt sold for deicing in the U.S. Our high use of salt results from a combination of local weather conditions and New York State's policy that bare pavement is to be maintained on State roads. A recent cost-benefit analysis which did not include environmental considerations concluded that there was an economic loss in Monroe County from salt use.

Deicing salt washes off roads in water and enters soil, plants, surface waters and ground water. This salt is known to damage and kill some plant life and to change the nature of soil. Accumulation of salt in Irondequoit Bay has changed the physical characteristics of the Bay. Spring mixing is inhibited, and fall mixing is delayed, which favors accumulation of nutrients in the Bay. In Penfield, N.Y. the mean chloride level in wells has more than doubled since 1935. Salt accumulation in other communities has led occasionally to the closing of private and public water supplies, and it has created a health problem for patients on low salt diets. Salinity has also limited industrial uses of water and greatly increased the rusting of cars, causing economic damage.

This bulletin documents the consequences of adding large amounts of salt to the ecosystem. Later bulletins will explain salt use practices in Monroe County and weigh the advantages and disadvantages of salt for deicing as used here.

Standards

There is always a problem of "permissible limits" in deciding whether or not a body of water is polluted. Two Federal agencies set standards: the Environmental Protection Agency and the U.S. Public Health Service. The EPA is beginning to set standards for polluting chemicals, but has not yet dealt with salt. The U.S. Public Health Service standards are based on human health or comfort, not on damage to plants or animals or other environmental criteria.

The Public Health Service standard declares that water containing more than 250 ppm (parts per million) of chloride is unfit for human consumption (27). This limit is set primarily on the basis of taste because healthy people can adjust to water containing as much as 2000ppm chloride without ill effect (30).

No limit has been set for either sodium or calcium in domestic water; however a 270 ppm limit for sodium is being considered (7). This level is high compared with the American Heart Association's suggestion of a 20 ppm maximum for sodium in drinking and cooking water for people on moderate or strict sodium diets (5,36). If contributed solely from sodium chloride, 270 ppm sodium would be accompanied by 404 ppm chloride(10).

Calcium concentrations as high as 1800 ppm in drinking water have been found harmless to man. High calcium levels can be a nuisance. "Hard" water increases soap consumption and leaves scale deposits on utensils, pipes, etc.

Thus, the only present legal standard of salt pollution in water is 250 ppm chloride, and the U.S. Public Health Service standard accepts water with more than 250 ppm chloride "if other more suitable supplies are not available". As a working term, therefore, water with over 250 ppm is considered here to be polluted.

<u>Levels of salt in fresh water</u>

Brine runoff entering major rivers is quickly diluted (15). Lakes, smaller streams and rivers, however, are vulnerable to pollution by deicing salt. Chloride levels of over 2,000 ppm were reported for the Menomonee, Kinnickinnic and Milwaukee rivers in Milwaukee in 1969, and attributed to highway salt runoff (5). Professor Diment and his students at the University of Rochester found that chloride levels at the mouth of Irondequoit Creek in Monroe County often exceed 250 ppm during the winter, and small streams feeding into Irondequoit Bay had salt concentrations which are much higher during the salting season. The chloride levels of the feeder streams in 1970-71 are presented in Table 1.

Irondequoit Bay provides a striking example of salt accumulation in a standing body of water. Chloride levels in the Bay have increased ten fold since 1910, with an especially rapid increase since the early 1950's when local use of deicing salts was greatly accelerated. The Bay receives water runoff from an area of 435 square kilometers (160 square miles), or 40% of the County total. In 1970 this drainage basin received 1% of the total deicing salt used in the U.S. In 1969-70 the chloride concentrations in surface waters of the Bay ranged from about 100 to 250 ppm, with deeper waters containing from 100 to 420 ppm chloride. At times, the chloride levels exceed the Public Health Service recommended limit for human consumption. Further, the salt laden waters which enter Irondequoit Bay have caused a vertical salt density gradient in the Bay which prevented the complete mixing of the water in the springs of 1970-72. The maximum depth of spring mixing has decreased yearly for the last three years. In addition, the fall mixing was delayed. Data from 1939-40 indicate that in the past, the waters of Irondequoit Bay have mixed completely to the bottom in both fall and spring. In 1939 the lower waters were almost oxygen depleted before mixing, but after mixing the water contained oxygen. In 1970-71 the bottom waters were without oxygen for most of the year. Current data suggest that if deicing salt usage continues to increase, the Bay may fail to mix completely even in the fall, decreasing the oxygen near the bottom even more. Reduced mixing tends to trap nutrients in the Bay, thus potentially accelerating its eutrofication. Thus highway salting has significantly altered the physical characteristics of Irondequoit Bay (2, 4).

Since 1939 the species of fish found in the Bay have changed. 16 species have either disappeared or decreased greatly in number, and 7 new ones have appeared (8). The new species tend to favor silty or brackish water.

A similar salt-induced stratification with loss of spring mixing has been observed in First Sister Lake in Michigan (5). The stratification resulted in extended periods during which there were very low oxygen levels in deeper water. In First Sister Lake salt stratification has been correlated with detrimental changes in animal and plant life in the lake.

Table 1.* Range and average chloride concentration (mg/liter; ppm) of small streams flowing directly into Irondequoit Bay.

Location or name of stream*	5 July 70 22 Nov 70	5 Dec 70 28 Mar 71	24 May 71 7 Aug 71
Southwest	261-364 305	281-1668 1250	307-585 409
Snider Island	95-324 272	491-2122 967	223-360 291
Densmore Creek	159-380 224	431-2502 1328	251-445 373
Northeast Storm Drain	153-507 268	478-46,000 8937	92-699 467
Helds Cove 1	89-258 189	281-13,300 2508	234-555 432
Helds Cove 2	218-176 244	245-400 304	not sampled
Glen Edith	193-411 342	248-6796 1327	323-546 438
Penfield STP	144-266 203	141-261 207	171-201 185
Buckaneer Restaurant	108-216 160	164-227 192	121-185 156
Rochester Canoe Club	144-198 176	not sampled	160-243 182

* Adapted from Diment et al. (4) Table 4 p.30
For specific locations of sampling sites see their Fig. 6, p.28

Levels of salt in local wells

The Health Department of Monroe County monitors salt levels in public water supply wells. All show increases in chloride in recent years. The chloride level in some wells in Penfield was tested in 1935 and again in 1973. There was great variation in chloride in the various wells, but when the data were averaged it showed that overall chloride concentration has more than doubled over the 38 year period.

Table 2. Chloride level in some wells in Penfield.

Year	Number of wells	Average Chloride Concentration
1935	96	70 ppm
1973	58	198 ppm

Subtracting the two means shows that there was an average increase of 128 ppm chloride in Penfield's wells between 1935 and 1973.

Only 19 of the same wells were examined in both 1935 and 1973. In these 19 wells the increase of chloride in the water averaged 214 ppm (20). Similar increases in chloride in private wells have been documented in other areas (16).

Known effects of excess salt in tap water

Chlorides can create problems for industry. Even in low concentrations they corrode various metals, including stainless steel. The Ohio River Valley Water Sanitation Commission recommends that salt levels in water for industrial use never exceed 250 ppm to avoid corrosion (5,30). Various industrial processes permit different salt tolerances. Water for dairy processing and photography must contain less than 20-30 ppm chloride; steel manufacturing is satisfied with chloride levels up to 175 ppm; food canning and freezing can be accomplished with up to 760 ppm chloride. Chlorine is, of course added to drinking water for disinfection, but its effect is minor since concentration added is on the order of 2 ppm.

Salt in drinking water can be harmful to people suffering from heart and kidney diseases. Specifically, a high level of sodium poses the greatest health hazard. Sodium ions are important in the retention of water in the body. The regulation of body water becomes defective in some diseases, and the sodium from salt aggravates this defect. Low salt or salt free diets are necessary in the treatment of heart disease, certain kidney diseases, edema, high blood pressure, cirrhosis of the liver, and during pregnancy. Most local salt studies have measured chloride, not sodium, but the measurements of sodium in Irondequoit Bay indicate that sodium is almost equal to chloride (on a molar basis)*(10).

Levels of salt in soil

Salt accumulation can change the character of soil. When brine washes into soil, the sodium ions tend to be exchanged for other ions and retained while most of the chloride runs off in ground water (14, 35). When sodium ions replace calcium ions in the soil, calcium is lost in the runoff (as calcium chloride). Such soils (sodic soils) have very poor aeration, hold less water, become easily compacted, and are much less favorable for plant growth than calcerous soils (1, 11, 25, 35). Chloride, which does accumulate in soils to a small extent, has no apparent effect on soil structure(9).

Along salted highways in Maine, salt has been shown to accumulate in the soil from year to year (14, 17). Each year soil farther from the highway is affected by the accumulating salt.

Sodic soils can be restored by treating them with calcium salts like calcium chloride or gypsum (calcium sulfate). Gypsum is preferred because of the low cost, but calcium chloride is much more soluble, and therefore more efficient (1, 35).

* Measurements of sodium by atomic absorption done by Dr. Richard Burton for Robert Bubeck's doctoral thesis.

Plant damage from highway salt

Most plant species are sensitive to salt damage, since they lack efficient mechanisms such as the animal's kidney for expelling salts. The symptoms of salt damage in plants are similar to those of drought, and are intensified by drought. Salt damage symptoms include retardation of growth: the plant parts are smaller, perhaps fewer in number. Other effects include early leaf coloration, marginal leaf scorch, shoot dieback, defoliation and death (19, 25, 35). Salt damage seems to make trees more disease prone (9, 19). Salt damaged grasses can show retarded growth and tip burn which progressively turns the entire blade brown and dead (28). Effects of salt on woody plants may be cumulative; over several years even low salt concentrations may cause a progressive decline (5, 11, 13).

Salt can damage plants in several ways: by increasing osmotic stress, by direct toxicity of salt ions on plant tissues, by causing a nutritional imbalance in plant tissues and soil (13).

Sodium, calcium and chloride ions contribute to water salinity. Their presence makes it more difficult for the plant to receive moisture from the soil. Progressive growth reduction, an increase in the salt content of tissues, injury and death can follow. Soil water salinity can be counteracted to some extent by watering heavily with low-salt water. Heavy rains usually do this.

Sodium and chloride ions are required by organisms in low amounts, but they are toxic to plants in higher amounts. Most salt enters plants through the roots, but stems and leaves may also receive salts following spray or dusting with highway salt (9, 13). Some salt-injured trees contain high concentrations of sodium chloride in twigs and leaves; these ions may have directly damaged the tissues. Calcium salts in high concentrations may also be specifically toxic to plants. Leaf scorch and death have been reported after calcium chloride was used for dust control (32).

The addition of certain salts upsets the balance of ions in soil and interferes with nutrient uptake by plants. While sodium is not vital to plants, it suppresses plant uptake of potassium, calcium and magnesium which are essential for normal plant growth. Excess chloride may also interfere with normal nutrient uptake (9).

All tree species are not equally sensitive to salt; sugar maples are among the most sensitive and oaks among the most tolerant. Woody trees and plants are generally more sensitive to salt than herbaceous plants, especially certain grasses. Salt sensitivity is related to the stage of plant development. Salinity can affect germination, vegetative growth or fruiting differentially depending on the species (13). Table 3 contains a classification of some common trees and shrubs according to salt sensitivity; Table 4 classifies vegetables and fruits in a similar manner. Most of the species listed grow in the Rochester area naturally, in cultivation, or as escapees.

Plant damage known to have occurred from deicing salts

It has been established that the amounts of deicing salts used in actual practice are harmful to roadside plants (33). For example, highway salting (mostly sodium chloride) is responsible for the decline of roadside sugar maples in New Hampshire (19, 31). Symptoms were more severe and frequent on trees close to and lower than the highway, circumstances which aided in distinguishing damage from other causes such as poor soil, auto exhaust or highway construction damage to roots.

In 1966-67 Washington D.C. experienced a particularly severe winter. The season of relatively heavy highway salting resulted in severe salt damage to vegetation the following summer. The effects were compounded by a subnormal rainfall in April which did little toward leaching the salts from the root zone (34).

Table 3. Classification of some common trees, shrubs, flowers and ornamentals according to salt tolerance (5, 24).

Tolerant*	Moderately Tolerant*	Sensitive or Intolerant*
black locust	arbor vitae	allysum
English oak	aspen	barberry
golden willow	balsam fir	black walnut
hawthorne	beech	blue spruce
honey locust	birch	douglas fir
petunia	blue spruce	European beech
red oak	cottonwood	European hornbeam
Russian olive	douglas fir	Italian poplar
Scotch elm	eastern red cedar	larch
silver poplar	golden willow	linden
tamarix	green ash	lombardy poplar
white oak	hard maple	pinks
white poplar	honeysuckle	red maple
	Japanese honeysuckle	rose
	ponderosa pine**	snapdragon
	red cedar	spirea
	Siberian crab	sugar maple
	white spruce	sycamore maple
		viburnum
		zinnia

Table 4. Salt tolerance of vegetable and fruit crops (5)

Tolerant*	Moderately Tolerant*	Sensitive*
asparagus	bell pepper	apple
garden beet	broccoli	apricot
kale	cabbage	avocado**
spinach	cantaloup	celery
	carrot	green bean
	cauliflower	lemon**
	cucumber	orange
	fig**	peach
	grape	pear
	lettuce	radish
	olive**	strawberry
	onion	
	pea	
	pomegranate**	
	potato	
	squash	
	sweet corn	
	sweet potato-yam**	
	tomato	

* Classification systems are not necessarily uniform; different researchers may use different criteria

** Not found in this (Rochester) area

The City of Rochester plants a variety of tree types along its streets; some are tolerant to salt, others susceptable (40). Sugar maples and apple trees along East River Road and East Henrietta Road are showing signs of salt damage.* Most of the documented salt damage to trees or grasses along highways occurred in areas where the amount of salt used was far lower than in Rochester. Twelve tons of salt per mile per year on Interstate highway 80 in Iowa killed grass up to 10 feet from the pavement (28). Rochester spreads at least 67 tons per road mile per year (18).

The Salt Institute suggests that salt damage to roadside vegetation can be alleviated by planting only salt resistant species along salted roads, leaving an open buffer area between trees and road, proper highway drainage and by limiting salt waste through careful spreader calibration and good management (29).

Effects of salt on animals

High salinity can result in several distinct physiological disorders in animals; most seem to be caused by the total osmotic effect rather than toxicity of any particular ion (26). Salt tolerance and requirements vary with species. Man seems less tolerant of high salinity than other animals.

Both sodium chloride and calcium chloride can be lethal to fish under experimental conditions. The tolerance of fresh or brackish water fish to salinity is related to several factors including age, temperature, rate of salt increase, other chemicals present in the water, and species of fish (30). The alewives, which are a nuisance in Lake Ontario, were originally a brackish water species: they prosper when salt levels increase in a lake.

Deicing additives and environmental hazard

Other chemicals may be added to salt for highway use in an attempt to prevent caking, or to reduce its corrosive properties.

Potassium ferric ferrocyanide or Prussian blue (a common ingredient in laundry blueing) and sodium ferrocyanide are commonly used as anti-caking agents, and other cyanide compounds have been tried. These additives coat salt crystals, preventing them from growing larger when the salt gets wet (10). Prussian blue is used in Monroe County in concentrations of up to 0.25 kg/metric ton (0.5 lb/ton) (4). It is not soluble in water and is of very low toxicity. It does not release cyanide upon acidification. Some other ferrocyanides do dissolve in water and under certain conditions will release cyanide. Sodium ferrocyanide (yellow prussiate of soda), when in solution, will liberate cyanide if exposed to sunlight (5). Cyanide is toxic to organisms, and the level of 0.2 ppm is grounds for rejection of a public water supply under the Public Health Service Drinking Water Standards of 1962 (27).

About 0.5 lb of sodium ferrocyanide is added to a ton of salt used to salt streets. The Salt Industry contends that this customary level is innocuous; no data has been found to support or refute the claim. The Environmental Protection Agency has agreed that too little information is available on the toxic nature of cyanide additives to salt, their fate, distribution and effect in the environment to justify their unquestioned use. The E.P.A. recommends research on salt additives now used in order to determine their potential hazards and safe levels of use, and also on the merits of alternative chemical additives or of using none (5). Cyanides (including the most toxic ones) are produced in nature and small amounts are found in some fruits and vegetables. There is no indication that the additives have approached a toxic level.

* Dr. Herman Forest, personal communication

In past years chromium-base rust inhibitors were mixed with deicing salt. Chromium reached a concentration in Minneapolis sewers well above the 0.05 ppm level set by the Public Health Service as sufficient to reject a public water supply. The single known supplier of chromium-treated salt discontinued its sale in 1971. According to the E.P.A. report "the chromium-treated salt was taken off the market because cost overshadowed its effectiveness as a corrosion inhibitor, and not principally due to environmental considerations" (5). Chromates are no longer used, but the lesson remains as a warning that additives have been used in total ignorance or unconcern for their potential harm.

Polyphosphate salts are the best rust inhibitors. Their use as additives to deicing salt was pioneered in Rochester, and they were added to every truckload of salt until a few years ago. This practice was discontinued by the City when research demonstrated that phosphate pollution increased nuisance growth of algae. The decision was supported for local waters in RCSI Bulletins Nos. 27, 28, and 29 (6, 3, 37).

Rusting of cars by salt affects every car owner in the region economically. In 1971 Jim Madden did a cost-benefit study on the use of salt for ice and snow control in Rochester (21). The only negative cost counted was the damage to automobiles because the author considered ecological costs such as occasional well contamination, incomplete mixing of the bay waters and damage to roadside vegetation minor. Even so, he found the cost to Rochester ($16 million) greater than the benefits ($12.5 million) which included a reduction in traffic accidents. He concludes that "although a further refinement of data is desirable before major decisions are made on the future use of deicing salt in Rochester, the basic assumption held by many public work officials that the benefits of using salt outweigh the costs is no longer tenable".

Perspective and needs

Deicing salts, both sodium and calcium chlorides, are known to accumulate in soils making them less suitable for plant growth, in groundwater supplies causing actual or potential problems for low-salt patients, and in standing bodies of water such as Irondequoit Bay altering the seasonal dynamics. Salts in soil and soil water, as well as wind blown salt, can damage and kill roadside vegetation, and may have a cumulative effect over a period of years. Salts seem less of a problem to animals, but excessive amounts cause a variety of physiological problems. The environmental effects of additives to salt are not well understood.

Apart from studies of Irondequoit Bay and Creek and the analysis of wells in Penfield, no account of local salt damage is available. However, the amount of deicing salt used in Monroe County is far higher than that which is known to cause environmental changes and damage elsewhere. It is possible that ecological accumulation and damage is occurring without our knowledge.

The RCSI would greatly appreciate a response from you who read this account. Do you know of any documented or suspected salt-induced changes in Monroe County that have not been mentioned above? Please write them down and send to the author at 151 Westland Avenue, Rochester, New York 14618.

References*

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* Only selected references are listed here. Complete list available from RCSI upon request.

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(5) Environmental Protection Agency, Water Quality Office publication "Environmental Impact of Highway Deicing". Water Pollution Control Research Series 11040 GKK 06/1971. 120pp. Originally from Zelazny, L.W. "Salt Tolerance of Roadside Vegetation" in the Proceedings of the Symposium: Pollutants in the Roadside Environment, pp 50-56. U. Conn. Feb. 29, 1968, Also from Bernstein, L., "Salt Tolerance of Fruit Crops", U.S. Dept. of Agriculture, Agricultural Information Bulletin No. 292. 8 pp., 1965. Also from Bernstein, L., "Salt Tolerance of Vegetable Crops in the West", U.S. Dept. of Agriculture, Agricultural Information Bulletin No. 205, 5 pp., 1959.

(6) Forest, H., D. Wilson, and G. Berg, "Rust Inhibitor and Water Pollution", RCSI Bulletin #27(W), May 1967

(8) Gittleman, Steven and Claire Buchanan, "A Survey of the Fish of Irondequoit Bay", RCSI Bulletin #130(W), Dec. 1971

(9) The Habitat School of Environment, Deicing Salts and the Environment. Prepared for Massachusetts and National Audubon Societies, Feb. 1972. 50 pp.

(18) Raymond Keefe of the Monroe County DPW in 1972 provided the figure of 250-300 miles of arterial streets in Rochester. Mr. Fitch, assistant director of the County DPW in 1973 estimated a total of 640 miles of all types of roads in the city of Rochester. According to Mr. Vicaretta, of the city DPW, a total of 43,318 tons of deicing salt were used in the city in the winter of 1971-72. If we assume that the salt was evenly spread over all city roads, the tonnage per mile for that year was about 67 tons salt/road mile/year. This estimate may be very low. Mr. Keefe stated in a discussion with the 1972 Salt Task Force that the city does not salt residential streets, except for danger spots. If all of this salt were spread on the 250-300 miles of arterial streets in Rochester, the amounts would be close to 144 tons salt/arterial road mile/year. The actual salt usage must lie somewhere between these two extremes, between 67 and 144 tons/road mile/year.

(19) Lacasse, N.L. and A.E. Rich, "Maple Decline in New Hampshire", Phytopathology 54:1071-1075, 1964

(20) Locksley, Wendy; personal communication

(21) Madden, Jim L., "The Use of Salt for Ice and Snow Control in Rochester; A Cost-Benefit Study", Master's Thesis. Systems Analysis Program Working Paper Series No. 7124, 1971

(23) Messner, Paul, Monroe County Water Authority, on the basis of maps on municipal water supply, October 1973, personal communication

(25) Prior, G.A. and P.M. Berthouex, "A Study of Salt Pollution of Soil by Highway Salting", in Highway Research Record No. 193, Environmental Considerations in the Use of Deicing Chemicals. **Publication of the Highway Research Board, National Research Council, Publication No. 1524, pp 8-21.**

(28) Roberts, E.C. and E.L. Zybura, "Effect of Sodium Chloride on Grasses for Roadside Use", in Highway Research Record No. 193, Environmental Considerations in the Use of Deicing Chemicals. OP.CIT. pp 35-42, 1967

(30) Schraufnagel, F.H., "Pollution Aspects Associated with Chemical Deicing", in the Highway Research Record No. 193, Environmental Considerations in Use of Deicing Chemicals. OP.CIT. pp 22-33, 1967

(37) Wilson, D.J., "Sewage Phosphates and Algae in Lake Ontario, II. Report of the Lake Erie Enforcement Conference Technical Committee", RCSI Bulletin #29(W), June 1967

(40) The City forester provided me with a list of plantings made fall 1971 and spring 1972.