
Management & Control of Diffuse Urban Snowmelt Pollution

Current snow and ice removal practices have made travel safer, but these practices have serious environmental consequences that need to be properly managed.

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Maintaining population mobility by automobile and air traffic during winter requires special and expensive snow and ice removal practices in the snowbelts of North America and other parts of the world (see Figure 1). Modern snow removal and deicing techniques have improved traffic safety and mobility to the point that differences between winter and off-winter non-storm traffic are minimal. However, providing bare pavements during winter requires massive applications of deicing and anti-icing chemicals that commonly threaten the environment and urban infrastructure (e.g., road pavements, buildings). In

the Northeastern U.S., snow may be acidic, which increases its corrosiveness, causing damage to infrastructure as well as increasing the elutriation of toxic metals.

Deicing Compounds

Currently, several deicing and anti-icing compounds are used by governmental agencies and private companies to maintain bare pavements during and after winter storms. According to how they impact water quality and the ecology, they can be divided into two categories:

- inorganic chloride salts with or without additives; and,
- organic compounds.

The former category exhibits toxic effects on biota residing in receiving water bodies and may also adversely impact roadside soils and vegetation. The latter category imposes a high biochemical oxygen demand (BOD) on the receiving waters and some compounds can also be toxic. Natural sands and other abrasives are also used to maintain safe winter driving conditions.

Chloride Salt. Before 1960, salt was used in very small amounts and only as an anti-freeze-

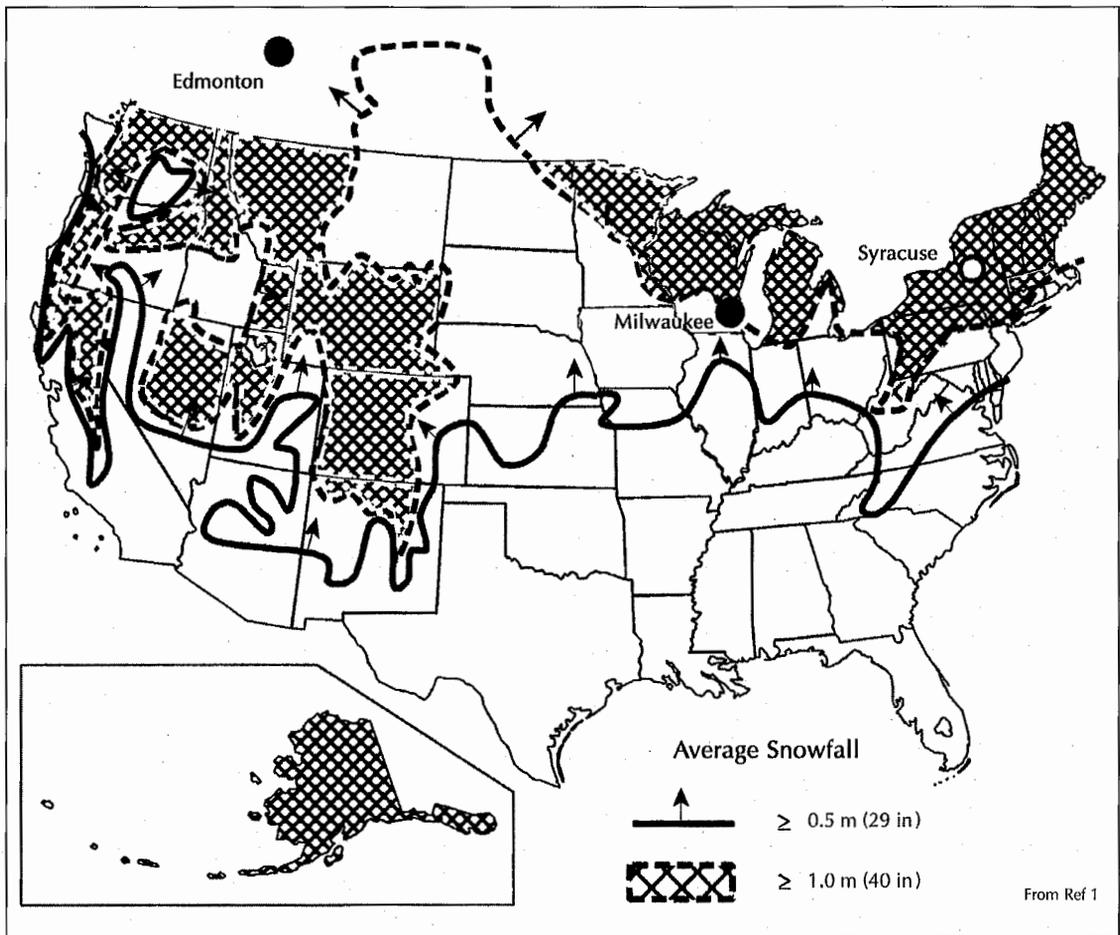


FIGURE 1. A map delineating snowbelt areas in the United States.

ing additive to abrasives. Since the 1960s, the use of chemicals, primarily salt, has increased in the United States to more than 10 million tons per year. To maintain safe driving in winter, agencies currently use rock salt (primarily sodium chloride), calcium chloride or abrasives mixed with salts, albeit in different proportions and application rates. The typical chemical composition of rock salt is given in Table 1. Table 2 presents the usage of chloride salt in some U.S. snowbelt communities. A typical application rate of sodium chloride salt is about 90 kilograms per lane kilometer per storm (320 pounds per lane mile per storm). Massachusetts and New York State have the highest road salt usage in the Northeast.² To prevent caking, sodium ferrocyanide — also known as yellow prussiate of soda (YPS) — is added to the salt. In its original form, YPS is

harmless. However, upon photo-decomposition in snowpack and snowmelt and other aquatic environments, very toxic hydrogen cyanide (HCN) can be released.^{3,4}

About half of the agencies responsible for maintaining population mobility use calcium chloride at lower temperatures, either as a liquid or as a dry mixture with salt (NaCl). This compound has a lower freezing point and is often applied when temperatures range from -25 to 0°C (-13 to $+32^{\circ}\text{F}$). The faster action and better efficacy at lower temperatures than NaCl salt is attributed to the higher solubility of CaCl_2 and better hygroscopic properties. Magnesium chloride (MgCl_2) is very similar to calcium chloride and has the same deicing properties. Massachusetts uses a 4:1 NaCl and CaCl_2 mixture for deicing and snow melting on roads.

TABLE 1.
Chemical Composition of Rock Salt Used on Highways & Streets

	Content by Weight
Water Insolubles (%)	0.2-2.5
Calcium Sulphate, CaSO ₄ (%)	0.5-0.9
Calcium Chloride, CaCl ₂ (%)	0.02-0.07
Magnesium Chloride, MgCl ₂ (%)	
Sodium Chloride, NaCl (%)	96.4-98.2
Chloride (Cl ⁻) (%)	58.6-59.7
Anticaking Additives (Sodium or Ferric Ferrocyanide) (μg/g)	75-120
Nitrates (μg/g)	<50
Chromium (μg/g)	2.1-3.1
Copper (μg/g)	2.8-4.2
Lead (μg/g)	4.9-6.6
Zinc (μg/g)	3.4-4.2

Note: Data From Ref 5.

Rock salt, when added at typical distribution rates to snow and ice, is effective to down to temperature of about -9°C (16°F). In a typical application during colder temperatures, the added salt softens the ice and may melt only about 10 percent of the total water content of the snow and ice layer of the treated surface. The additional impact of traffic converts snow to liquid slush.

Calcium chloride and magnesium chloride are applied as granules or as a liquid. The liquid form provides for a more efficient use of the deicing compound since less is needed on a given stretch of road. Therefore, when liquid CaCl₂ or MgCl₂ is used the overall cost of maintaining road safety during winter may be about the same or even less compared with rock salt. Also, cyanide additives used with rock salt to prevent caking do not need to be present in the liquid deicers. Calcium and magnesium ions in the deicing compounds buffer, to some degree, the adverse effects of the acid precipitation. They also reduce the toxicity of toxic metals elutriated into snowmelt from the infrastructure (e.g., copper and zinc gutters) and deposited by traffic on the roads. Calcium and magnesium improve soil characteristics because the adverse impact

on soil fertility is proportional to the Na:(Ca+Mg) ratio.

Organic Compounds. Several organic compounds have been developed in the last ten to fifteen years as a substitute for chloride salt or as a salt additive to reduce salt application rates. The most widely used compounds are calcium magnesium acetate (CMA), an agriculturally derived compound and glycols. CMA and the agriculturally derived compound are used on roads and parking lots; glycols are used for airport and aircraft deicing and anti-icing. (Use of glycols and airport snowmelt pollution, although significant, will not be discussed here.)

CMA is a man-made powdered mixture of dolomite lime and acetic acid. Field studies have shown that the capability of CMA to melt ice is as good as salt at lower application rates. CMA is far less corrosive than salt and is biodegradable. However, the price of CMA is approximately twenty times the average price of salt.

CMA works well when mixed with sand, which helps to improve adhesion of the chemical to the road surface until melting action begins. It also adheres better to snow and ice than salt. It has performed acceptably as a

TABLE 2.
Reported Winter Highway Deicer Usage in
Selected North American Metro Areas

Metro Area	Deicer	Central City		County		State DOT in Metro District	
		Total	Rate/Lane km	Total	Rate/Lane km	Total	Rate/Lane km
Buffalo (NY)	Salt	NA	NA	60,000 t	15 t	112,000 t	20 t
	CaCl ₂	NA	NA	NA		20 m ³	3.76 lit
Cleveland (OH)	Salt	57,200 t	11.9 t	5,720 t	64.4 t	78,863 t	26.3 t
	CaCl ₂	5.5 t	0.001 t	NA	NA	671 m ³	227 lit
Detroit (MI)	Salt	36,330 t	7.2 t	62,060 t	4.85 t	127,325 t	16.2 t
	CaCl ₂	NA	NA	9.18 m ³	0.71 lit	NA	NA
Duluth (MN)	Salt	NA	NA	11,800 t	2.1 t	22,485 t	6.8 t
	CaCl ₂	NA	NA	7.56 m ³	1.42 lit	NA	NA
Edmonton (ALB)	Salt		1.24 t ^a	b	b	b	b
	Abras	13,741 t ^a	13.3 t				
	CaCl ₂	141,394 t 59.15 m ³	5.5 lit				
Milwaukee (WI)	Salt	58,187 t	4.57 t	58,078 t	23.54 t	c	c
	CaCl ₂	320.5 m ³	28 lit	637.7 m ³	258.3 lit	c	c
	CaCl ₂			274.2 t	0.11 t	c	c
<i>Other Wisconsin</i>							
Brookfield	Salt	3,632 t ^a	4.12 t	NA	NA	NA	NA
	Madison	Salt	7,349 t	2.23 t	NA	NA	NA
Syracuse (NY) ^d	Salt	31,820 t	24.75 t	45,455 t	39.0 t	71,040 t	18.80 t
	CaCl ₂					73 m ³	19.3 lit
	Abras					37,808 t	10.0 t
Toronto (ONT)	Salt	NA	NA	42,906 t ^e	12 t ^e	91,502 t ^f	10.9 t ^f
Massachusetts	NaCl ₂ / CaCl ₂ Mix	NA	NA	NA	NA	NA	11.2 t
New York State	Salt	NA	NA	NA	NA	NA	9.3 t

Notes: a. Generally mixed with a substantial portion of abrasives.

b. City performs maintenance on all highways.

c. Included partly in Milwaukee County total.

d. Syracuse from 1996-1997.

e. Metro Transportation for area.

f. Provincial district in Toronto.

Units in this table are SI. To convert to their U.S. equivalents multiply SI tons to U.S. tons by 1.1, liters to gallons by 0.26, area SI tons/km to U.S. tons/mile by 1.77, and liters/km to gallons/mile by 0.42.

NA = not available.

Data from Ref 5.

deicer, although not in the same manner or quite as effectively or consistently as salt. Compared to salt, it is slower acting and less effective in freezing rain, drier snowstorms and light traffic conditions. Because of its

lower density and greater volume requirements, it requires greater truck capacity and more enclosed storage space than salt. CMA is well suited for being used in a liquid form during anti-icing treatments.⁸

CMA is highly biodegradable and exhibits high BOD. The total theoretical BOD_t (or COD) is 0.9 grams of O_2 per gram of CMA or 1.08 grams of O_2 per gram of acetate, which may result in a BOD_5 of about 0.6 to 0.7 grams O_2 per gram of CMA. CMA is less mobile in soil and is unlikely to reach groundwater. It will degrade in soil where it will have an effective half-life of about two days at a temperature of $7^\circ C$ ($45^\circ F$). Unlike sodium chloride that degrades soil by replacing calcium in soil/clay minerals with sodium, the calcium and magnesium cations derived from CMA have high affinities for cation exchange sites on soil particles and may actually restore soil properties that could have been damaged by sodium from previous salt (NaCl) discharges. CMA improves the pH buffering capacity of soil receiving acid inputs and, over time, improves the metal retention capacity of soil. This pH buffering capacity may be important, considering the fact that urban precipitation in the Northeast could be acidic. The University of Massachusetts has been investigating the efficacy and applicability of CMA and other evolving deicing compounds to the state highways and conditions.

The agriculturally derived compound is a liquid byproduct produced from various sources.⁸ It is a concentrated liquid residue of the fermentation and distillation of alcohol (ethanol) made from various raw materials such as cane or beet sugar syrup, corn or barley. It has an appearance and consistency similar to molasses. Similar to CMA, this compound can be applied either alone or in a mixture with chloride salts. When used as an additive to salt, about 25 to 42 liters of the compound is mixed with 1 ton of salt (6 to 10 gallons per U.S. ton). Doing so improves the deicing capability of salt and enables the reduction of salt application rates to 42 to 60 kilograms of salt per compound mixture per lane kilometer per storm (150 to 200 pounds per lane mile per storm), which is about one-half of the application rate of rock salt alone. When used alone, the application rate is about 3 liters per 100 square meters (0.9 ounces per square yard) of treated surface (e.g., parking lot).

Table 3 shows the approximate chemical composition of this compound. One can immediately recognize that it contains several

TABLE 3.
Approximate Composition of the
Agriculturally Derived Compound

Specific Gravity	1.23
Dissolved Solids	42–52 percent
BOD_5	0.5 g of O_2 /g of fluid = 407 g of O_2 /L of fluid
Phosphorus	10,000 mg/L (0.83 %)
Cyanide	0.15 mg/L (0.12 ppm)
Copper	0.8 mg/L (0.65 ppm)
Zinc	55 mg/L (45 ppm)

Notes: Data From Ref 8.

constituents that may be potentially harmful to the ecology of receiving water. High phosphorus, cyanide and zinc content measured during a Wisconsin DOT study are potentially troublesome.⁸ Phosphorus is a nutrient that stimulates the growth of algae and cyanide can be potentially toxic. The distributors and manufacturers claim that phosphorus is mostly (approximately 90 percent) in a form not directly available to algae; however, it does leave some phosphate (about 10 percent) available to algal growths.

Snowmelt Pollution

In northern climates, some of the highest urban runoff pollutant concentrations occur during winter and early spring when urban managers are least able to implement effective pollution controls. Winter snowmelt runoff from urban areas has serious impacts on U.S. waterways. The snowmelt runoff is laden with solids, oxygen-demanding substances, cyanides, nutrients, metals, polyaromatic hydrocarbons (PAHs) and other toxic chemicals that periodically shock the receiving waterways with the highest pollutant loadings of the entire year. A major contributor to the winter runoff problem is the use of deicing chemicals and abrasive/sand mixtures on urban streets. To complicate the problem, municipalities and commercial and industrial entities have limited abilities to manage this runoff because conventional urban best man-

TABLE 4.
**Concentrations of Pollutants in Lincoln Creek (Milwaukee),
30th Ave. Storm Sewer Outfall (Edmonton) & Syracuse**

Snowmelt Sampling Location		Total Suspended Solids (mg/L)	Dissolved Solids (mg/L)	COD (mg/L)	Total Phosphorus (mg/L)	TKN (mg/L)	Nitrite & Nitrate (mg/L)	Total Cyanide (µg/L)
Lincoln Creek (Milwaukee)	Mean	46	2,874	57	0.43	1.1	0.97	31
	Range	6-173	732-5,650	14-213	0.19-0.62	0.3-2.35	0.57-1.46	ND-45
30th Ave. Sewer (Edmonton)	Mean	259	655*	167	1.08	4.3	1.19	≤5
	Range	16-1,322	180-3,980*	41-715	0.26-9.7	0.8-12	0.13-4.1	ND-7
Syracuse — Creeks								
Meadow Brook (mostly residential)	Mean	33	2,453	20	0.38	0.53	0.81	48
	Range	3-9	252-6,000	5-50	0.06-1.38	0.2-1.2	0.55-1.55	<2-167
Ley Creek (urban)	Mean	7.6	1,180	37	0.25	0.7	0.61	8
	Range	1-22	610-1,830	21-60	0.034-0.96	0.5-0.8	0.51-0.67	<2-24
Nine Mile Creek (rural)	Mean	20	497	9.2	0.10	0.48	1.18	≤2
	Range	2-99	252-662	3-22	0.04-0.386	0.2-1.2	1.0-1.55	<2-2
Syracuse — Storm Sewers								
Meadow Brook Basin	Mean	28	10,527	69	0.117	0.65	1.0	Not Measured
	Range	4-52	5,240-17,000	39-98	0.06-0.183	0.5-0.9	0.82-1.52	
LeMoyné Ave. Outlet in Ley Creek Basin	Mean	216	9,946	85	0.23	0.76	0.9	
	Range	14-434	2,510-28,700	55-165	0.114-0.34	0.3-1.0	0.84-0.89	
Industrial in Nine Mile Creek Basin	Mean	37	808	15	0.15	0.3	1.04	
	Range	5-139	558-1,270	3-46	0.03-0.6	0.1-0.4	0.65-1.50	

Notes: * Estimated from measured specific conductivity.

TKN = Total Kjeldahl Nitrogen = Total ammonium + organic nitrogen

agement practices (BMPs) either do not function or have reduced efficiency during winter snow and ice conditions.

Comprehensive research on snowmelt pollution and its abatement sponsored by the Water Environment Research Foundation was conducted in Milwaukee; Edmonton, Canada; and Syracuse, New York.⁹ Highway and city street maintenance agencies in Milwaukee and Syracuse use salt for deicing and the city of Edmonton relies on abrasives that consist of a mixture of sand and salt. Table 4 presents the measured concentrations of pollutants in snowmelt in the three investigated communities.

The following concerns related to the impact of winter urban road/highway snow-

melt on the integrity of urban receiving waters were outlined in that report and derived publications: direct effects of elevated salt concentrations in snowmelt discharges on receiving waters, cyanides, greater concentrations of pollutants, increased toxicity of metals, enrichment and "first flush" effects, and the linear increase of accumulated solids on impervious surfaces.^{9,10}

Direct Effects of Elevated Salt Concentrations in Snowmelt Discharges on Receiving Waters. Both salinity and chloride concentrations are regulated by the states. Massachusetts has respective water quality standards of 250 milligrams per liter (mg/L) for chlorides and 500 mg/L for salinity for Class A waters. However, salt and chloride concentrations of

snowmelt runoff after the use of highway deicing salts during winter to maintain bare pavements were measured in thousands mg/L in the receiving waters studied in Wisconsin and New York State. Salinity concentrations of urban snowmelt generated flows in streams and sewer outlets as high as 17,000 mg/L were observed in Syracuse and about 5,600 mg/L in Milwaukee.^{5,9} These results represent a salinity increase of two to three orders of magnitude over typical non-winter urban runoff. These transient high salinity concentrations could create toxic shock to the biota (fish and macroinvertebrates) residing in urban receiving waters. Since Massachusetts relies on surface waters for water supply, reduced salt usage in watersheds providing (unfiltered) drinking water is crucial. Concerns with chloride and salinity loads in the New York City water supply reservoirs were expressed by Wegner and Yaggi.²

Cyanides. Commercial salts used for deicing contain mildly toxic ferrocyanide compounds that are anticaking agents. However, these complex cyanide compounds may degrade by photo-decomposition in snowmelt and/or receiving waters and become toxic free cyanides (HCN). The quantity of the cyanide, though very small (about 0.01 percent by dry weight in salt), may be viewed as a water quality problem in water bodies receiving large flows of salt-induced snowmelt runoff without sufficient dilution. Cyanide in either free form (HCN) or measured as total cyanide is regulated by federal and state water quality criteria and standards. For example, chronic toxicity (Criterion Continuous Concentrations) cyanide criteria are 5 micrograms per liter ($\mu\text{g/L}$) for fresh waters and 1 $\mu\text{g/L}$ for marine waters, respectively. These limits can be exceeded during snowmelt events.

Greater Concentrations of Pollutants. Except for suspended solids, pollutants in snowmelt from highways, urban streets and airports occur at higher concentrations than in non-winter runoff. Figures 2 and 3 show a comparison of winter and non-winter concentrations of pollutants in Lincoln Creek (Milwaukee). The creek lies within the confines of the city of Milwaukee and its watershed is fully urban-

ized. There are no point sources of pollution discharging in the creek.

Increased Toxicity of Metals. During winter, salt laden snowmelt may have a higher proportion of dissolved metals. It is known that the dissolved divalent ionic form of trace metals is toxic to the biota, while the adsorbed or particulate fraction is considered biologically unavailable. Figure 4 shows a relation of the partitioning coefficient for metals to the chloride levels calculated from field and laboratory samples. The partitioning coefficient, Π (in L/g), relates the particulate concentration of the metal, r (in $\mu\text{g/g}$ of solids), to its dissociated (dissolved) fraction, C_d , in $\mu\text{g/L}$:

$$r = \Pi C_d$$

This equation can be expanded to relate dissolved concentration, c_d , to total pollutant concentration, c_T :

$$c_d = c_T / (1 + \Pi m_{ss})$$

where m_{ss} is the concentration of suspended solids in g/L.

As the partition coefficient decreases with the increased chloride content, more metal at a given concentration of suspended solids is converted to the dissociated divalent toxic form. Particulate metals tied to solids or precipitated are considered nontoxic.

Enrichment and "First Flush" Effects. Snowmelt enrichment by ionic contaminants was observed by many investigators. This phenomenon describes a chemical process occurring in the snowpack by which ions are rejected from the crystalline lattice of snow during repeated cycles of freezing and thawing. These ions stay in the snowpack liquid that is always present, albeit in very small quantities. Upon melting, these dissolved pollutants become available for wash-off during the first stage of the snowmelt and occur in the first flush at concentrations that may significantly exceed the average measured concentrations in the liquified snowpack. This process affects dissolved/dissociated pollutants such as hydrogen ion content (pH), nitrates, total dissolved solids, chlorides and COD.^{11,12}

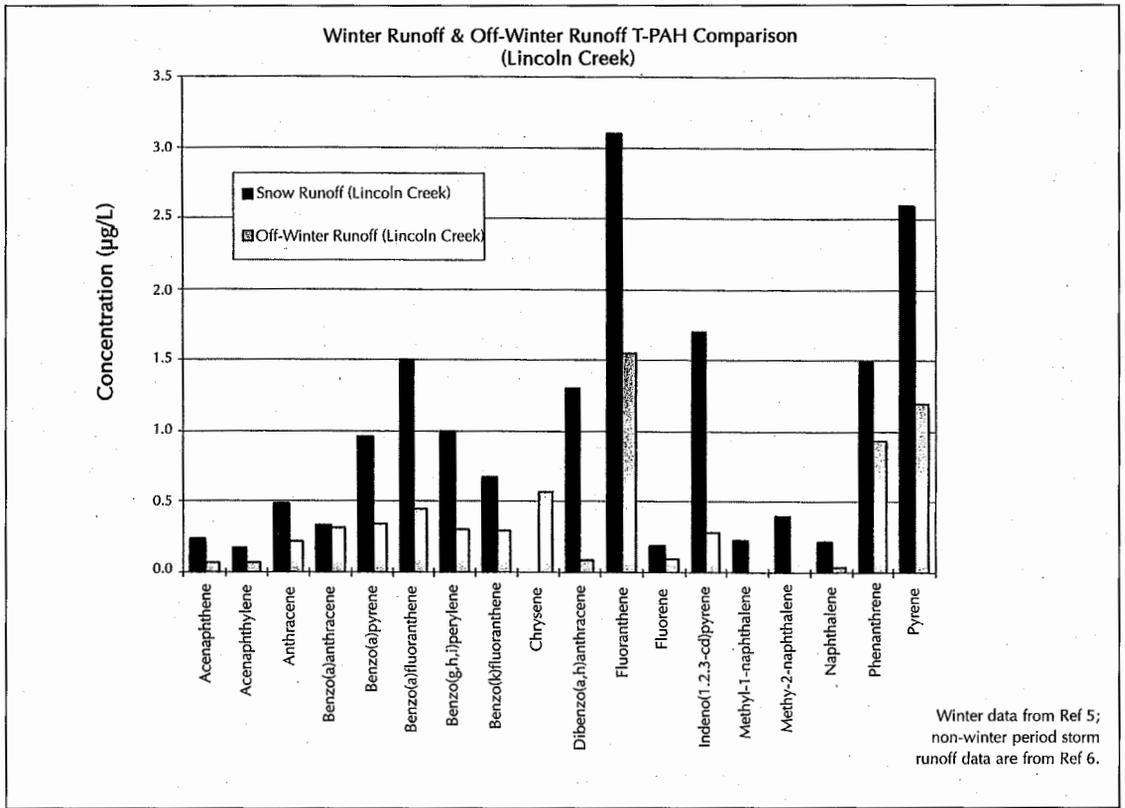


FIGURE 2. Lincoln Creek (Milwaukee) winter and off-winter PAHs comparison.

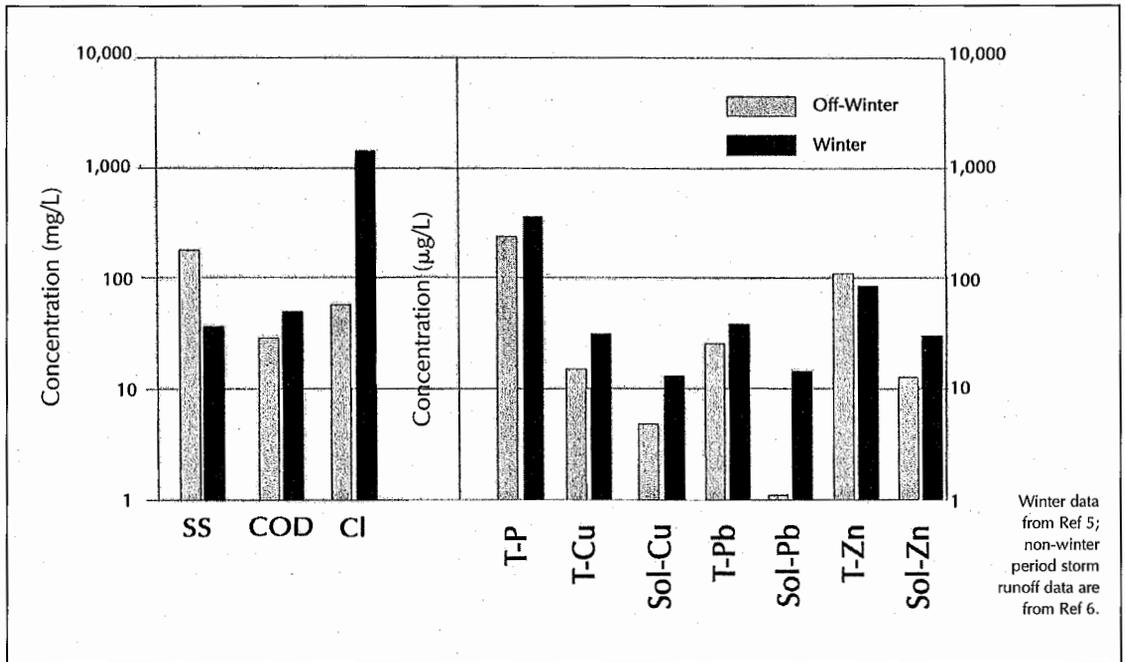


FIGURE 3. Comparison of winter (snowmelt) and off-winter (stormwater) concentrations of conventional pollutants in Lincoln Creek.

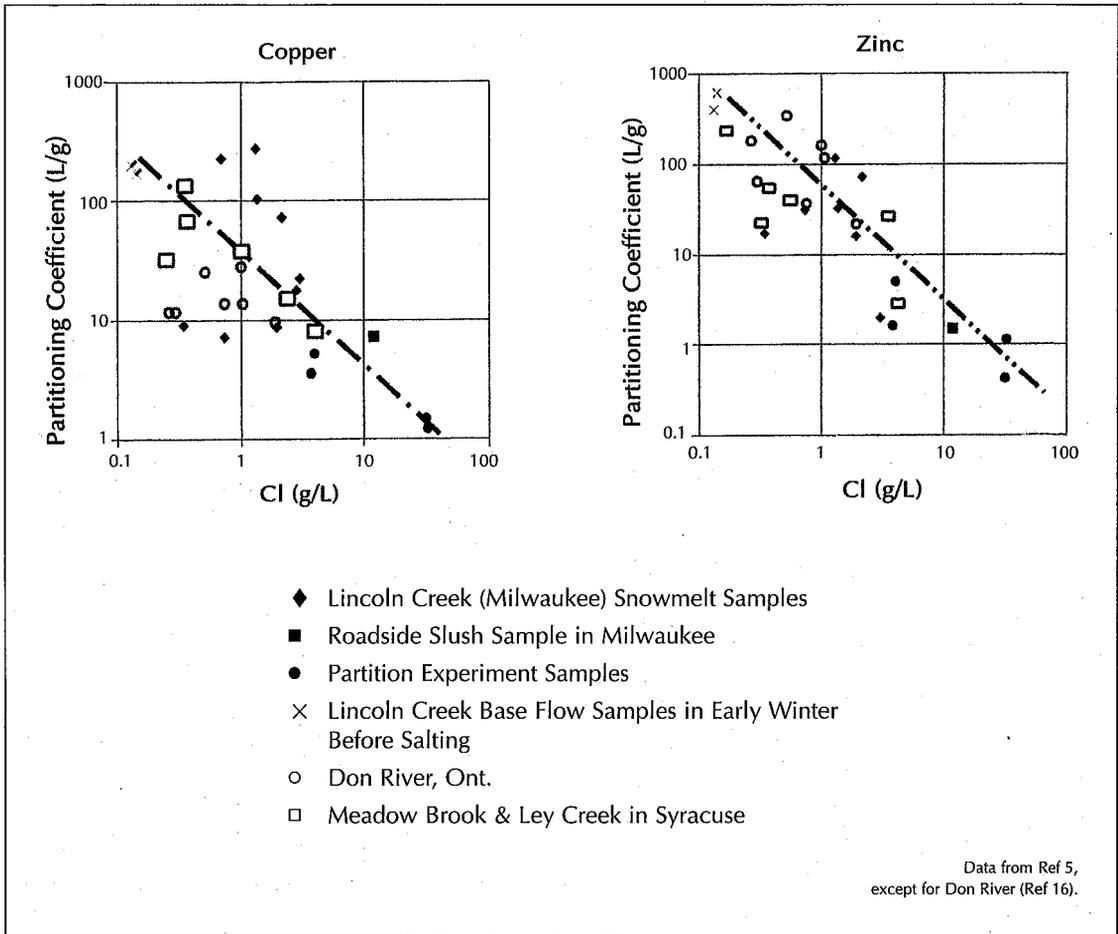


FIGURE 4. Relationship of the metal partition coefficient, Π , to the chloride (salinity) content of snowmelt.

The first flush phenomenon, known to exist also during off-winter in combined sewer overflows and stormwater runoff, is in winter caused by chemically induced flows. These flows originate from road surfaces after the application of deicing chemicals. The volume of these chemically induced flows may not be great; however, the concentrations of the pollutants are very high.

Linear Increase of Accumulated Solids on Impervious Surfaces. The removal of particles from street surfaces by wind does not occur when snow piles accumulate along streets after plowing and/or when ice has formed in gutters. Furthermore, both street snow piles and accumulated unplowed snow are almost perfect traps for atmospheric (snow and dry) deposition and deposits from other sources

such as traffic emissions and vehicle corrosion. In places where snow can remain on the ground for weeks or even months, the accumulated snow stores pollutants at higher quantities than it would during a no-snow period. Annual peaks of loads of some pollutants to receiving water bodies occur during spring snowmelt.¹³ Figure 5 shows buildup of solids on the side of an urban street in Milwaukee during the year. A good spring sweeping of road sides should be implemented.

Managing Snowmelt Pollution & Minimizing Adverse Ecological Impacts

Currently, pressure on highway and city road management agencies is increasing to reduce

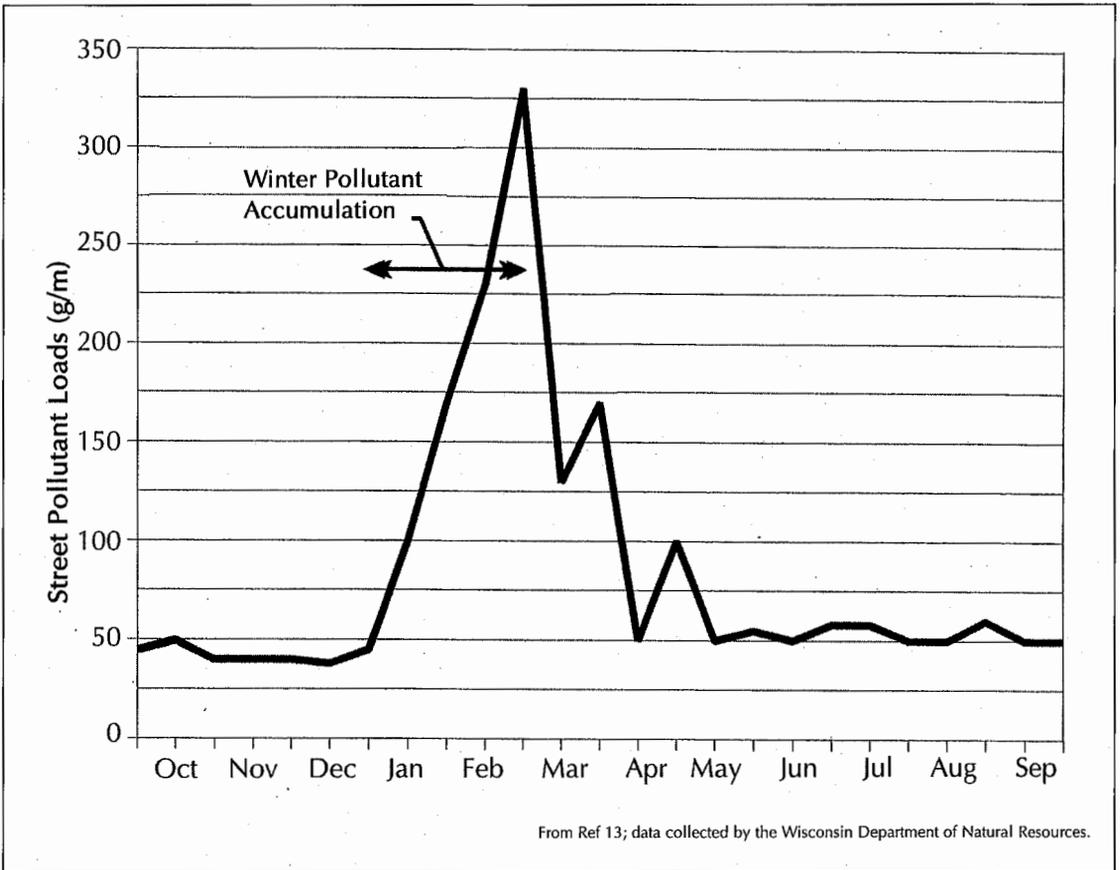


FIGURE 5. Annual variation of street surface (curb storage) accumulation of dust and dirt in a Milwaukee experiential watershed.

the adverse environmental/ecological consequences of road deicing and snow removal while continuing to provide safe driving conditions. This pressure has led to extensive research and to the development of alternative deicers/snow removal compounds such as CMA, agriculturally derived compounds, as well as additives to retard or reduce vehicle and highway infrastructure corrosion.

Research funded by the Water Environment Research Foundation has established that the source of the pollution problem of snow and snowmelt in urban areas and inter-urban transportation systems is limited to impervious areas and a strip of pervious land, extending about 10 meters from the road.⁵ The quality of snow more than 10 meters away from the road approaches background levels. The spray impact of deicing chemicals does not extend significantly beyond the 10-meter dis-

tance from salted roads unless the snow is transported by snow removing machines far away from the road.

Strategy of the Winter Management of Urban Pollution. The strategy for winter urban pollution management can be broken down into two approaches that should be implemented simultaneously:¹⁴

- Reducing the use of deicing compounds, selecting more environmentally safe deicing and anti-icing chemicals, and better snow removal practices.
- Using best management practices to control residual pollution.

Both management practices must be considered in the watershed context.

Recent Developments in the Use of Highway Deicing Chemical & Snow Removal Practices. In

the pre-1990 period, in many older urban areas in North America, the typical winter road maintenance scenario was to react according to the weather forecast for the community, mobilize winter maintenance crews and take action after the beginning of the storm. Usually, a road deicing operation was undertaken with salt or salt/abrasive mixtures based on the forecast with deicing being the first operation and plowing resorted to when snow accumulated to 5 to 7.5 centimeters (2 to 3 inches). Often, when forecasts were inaccurate, or when unusual conditions occurred, snowpack or icepack would occasionally develop that was then "burned off" with large amounts of salt or calcium chloride, depending on the temperature.

The serious ecological concern created by using deicing chemicals is prompting efforts to develop new chemicals, new combinations of chemicals and new techniques for using and applying these chemicals, either as a deicer or anti-icing agents. Much of the impetus for changing methods of deicing and making anti-icing an acceptable alternative in the arsenal of U.S. winter maintenance practices is coming from Europe and Japan. It includes incorporating modern computer technology into both weather and pavement temperature forecasts as well as using modern equipment spreaders.

Acceptance of pre-wetting the solid chemicals (e.g., salt, abrasive mixtures) or using brine instead of solid salt granules has been growing in Europe. The objectives of applying brine instead of dry or pre-wetted salt include instant reaction, increased spreading speed, reduced consumption rates of salt and faster drying of deicing roads. The effects have been judged by Norway's Public Road Administration to be very good when brine is applied as a preventive action before snowfall or icy conditions and after the formation of frost or a thin layer of ice. It was estimated that salt use could be cut as much as 50 percent if all the new technologies, such as a road weather information system (RWIS), thermal mapping of pavements, spreader equipment development (ability to use both liquid and solid on the same vehicle) and anti-icing take hold in the United States. Liquid ice-control chemicals have the advantage of offering better control

and more immediate effectiveness. Consequently, smaller amounts can be used. In this way, implementation of these new technologies is cost effective. However, liquid chemicals should not be used when freezing rain or above freezing temperatures with wet snow are forecasted because liquid precipitation will wash out the chemicals more readily. Furthermore, chemicals in liquid brine form do not require anticaking agents (cyanides).

Use of a RWIS is growing rapidly in the United States but the intensity is still lagging behind Europe, especially Scandinavia. These systems are used for monitoring and collecting site-specific pavement and weather information, using a combination of sensing devices, communication equipment, computer networks and meteorology. Sensors monitor weather information, such as wind speed, air temperature, dew point, visibility and precipitation. Vermont is using infrared sensors on the bottom of snow plows to measure the actual temperature of the roadway as the trucks pass over, allowing for a more accurate calculation of the amount of salt needed. Doing so has reduced the amount of salt spread down by 20 to 30 percent. In more complex systems, sensors monitor pavement temperature and moisture and can estimate the amount of chemicals present on the road surface. The roadside and pavement monitoring equipment is sometimes wired to a remote processing unit that provides communication to a central processing unit accessible to winter maintenance personnel. The use of these stations allows agencies to improve dramatically the ability to forecast site-specific precipitation and air and pavement temperatures. These documented reductions can be especially significant in low salt use drinking water reservoir watersheds in Massachusetts.

As noted by the federal Transportation Research Board (TRB), highway agencies are lacking guidance on optimal selection and application rates. Research is underway by the TRB to prepare such guidelines. Currently, there is no computerized expert system available to these agencies for on-line, real-time evaluation of the expected snowfall and its environmental consequences caused by road deicing and snow removal operations.

Salinity, cyanide and dissolved metal toxic shock to the biota in receiving water bodies may not be a problem if sand/salt abrasives are used instead of deicing salt alone. A sand-salt mixture may be a deicer of choice for many communities that do not have combined sewers or where storm sewer clogging is not a problem. Abrasives themselves, however, can be a source of problems. Higher phosphorus and COD/BOD concentrations have been observed in watersheds where salt-abrasive mixtures are used and the sand delivered to the receiving water bodies may impair the habitat. In communities with storm sewers, grass filters and buffers between roads, as well as storm inlets could be used to prevent the clogging of sewers by grit and excessive sediment loads.

Calcium chloride brine is the most efficient anti-icing chemical that also has significant environmental benefits (such as a reduction of metal toxicity). It has been used widely in Europe and tried recently in the United States. As pointed out previously, Massachusetts is using a 4:1 mixture of sodium chloride with calcium chloride for deicing that has both environmental and economic benefits. However, at very low temperatures, abrasives may have to be used. Research should continue on the use of CMA and agriculturally derived compounds when mixed with salt. These types of mixtures may reduce the salt application rate even further; however, they may have additional environmental consequences such as BOD and phosphate enrichment of the receiving waters. CMA may be a deicer of choice in areas suffering from the ecological effects of acid precipitation because of its pH buffering and soil improving capability. However, high BOD and its effect on the oxygen resources of the receiving water bodies are significant environmental drawbacks. Also, the higher cost of CMA, in comparison to salt and salt/sand mixtures, may be a problem.

Snowmelt Pollution Management in the Watershed Context. Usually combined sewers and connected downstream treatment facilities have excess capacity to accommodate some wet weather flow inputs. Because of very slow melting rates, in contrast to stormwater runoff, the snowmelt rate is less

than the critical rainfall intensity rate that initiates an overflow. Therefore, the pollution from snowmelt usually can be handled by a treatment plant. If storage is available, almost all of the polluted snowmelt can be captured and treated. Snowmelt induced by heat can also be treated adequately. However, rain falling on snowpack may cause an overflow.

Roads and strips of pervious land up to 10 meters (30 feet) away from the impervious surfaces (usually roadside swales) receive polluted snowmelt and are also affected by the spraying of deicing chemicals. Management relies on infiltration and attenuation of snowmelt pollution in roadside grassed buffers (filters).

Many potential BMPs have been developed and implemented to control non-winter urban and highway runoff, often without considering winter snowmelt pollution. However, the management of winter pollution is difficult because the majority of BMPs implemented for stormwater pollution control are inoperative (e.g., street sweeping) and/or inefficient (e.g., common ponds and wetlands) during winter. Pollution originates primarily from impervious areas.

Winter problems of conventional urban BMPs are due to the following factors:¹⁵

- The conveyance systems and soils are frozen.
- Particle settling is reduced due to higher viscosity or flows at freezing or subfreezing (due to salting) temperatures and due to increased density.
- A thick layer of ice inhibits the functioning of ponds.
- Winter accumulation of dissolved or dissociated pollutants in the snowpack can be washed away by a single snowmelt, especially if combined with rainfall.
- Large quantities of particulate pollutants are not carried away by snowmelt and may remain on the urban surface. They are subsequently washed away by spring rainfall (storm) runoff.
- Street sweeping cannot be carried out when snow and ice are on streets.
- Biodecomposition of deposited organics is minimal.

TABLE 5.
The Effectiveness of Stormwater Ponds in Minnesota & Wisconsin in Treating Runoff & Snowmelt

Pond	Percent Pollutant Removal								
	Event	TSS	VSS	Total P	Dissolved P	COD	TKN	NO ₂	Total Pb
McCarrons (0.97 ha)*	Snowmelt	58	58	41	38	50	22	13	40
	Rainfall	91	95	78	57	90	88	60	85
Lake Ridge (0.37 ha)*	Snowmelt	72 63	10	6	—	10	19	18	
	Rainfall	90	70	61	11	—	50	10	73
McKnight Basin (2.24 ha)*	Snowmelt	85 48	30	11	—	10	8	59	
	Rainfall	85	67	48	11	—	31	24	67
Woodbury (0.15 ha)*	Snowmelt	-60	-46	-17	-12	—	-27	4	-40
	Rainfall	46	32	24	21	—	14	18	42
Monroe Street Detention Pond**	Snowmelt	50	10	22	37	20	10	1	NC
	Rainfall	88 45	42	41	59	38	65	71	NC

Notes: * Minneapolis-St. Paul lakes & ponds (data from Ref 15).

** Monroe Street detention pond, Madison (data from Ref 17).

- Due to higher salt contents, the dissolved fractions of some pollutants (e.g., metals) are higher.

Table 5 shows the removal efficiencies of ponds in Minnesota and Wisconsin during winter operation. Of note are negative or negligible efficiencies for nutrients and metals. The reason for these poor efficiencies to treat metal pollution is the reduction of the partition coefficient by increased salinity, explained previously and shown in Figure 4, which may release previously (during the preceding non-winter period) accumulated metals and nutrients from the sediments.

BMPs for Winter Snowmelt Pollution Control. Although the efficiency of many BMPs, including ponds, is reduced during winter, ponds can become a key component of winter pollution management programs.¹⁴ Ponds may be preferable to wetlands because wetlands are dormant during winter and often become a source of pollution. However, typical simple wet and dry ponds and wetlands designed for stormwater pollution and volume controls are not efficient for controlling snowmelt pollution. To mitigate the problems with the winter performance of ponds,

these facilities can be designed with enough capacity to allow settling after ice is formed and provide some treatment by infiltration. One design that would function well under wintry conditions is an extended dry pond used in stormwater pollution abatement (see Figure 6). Such ponds are generally without standing water and their porous bottoms are relatively dry between snow storms. No ice layer would normally be formed during the winter period and the flow rates in the ponds would be relatively small and in most cases would be constituted from the chemically induced snowmelt and pavement melt. These "first flush" flows could infiltrate through the porous bottom and receive treatment by filtration. As the volume of the melt increases and the flow rate exceeds the capacity of the underdrains, the pond volume would fill and the pond would function as a wet detention pond and store the heavily polluted flows until the volume in the pond reaches the orifice outlet control device. Existing dry ponds could be used for storage and equalization of the first flush that can then be diverted for treatment (e.g., using excess treatment capacity of wastewater treatment works during winter).

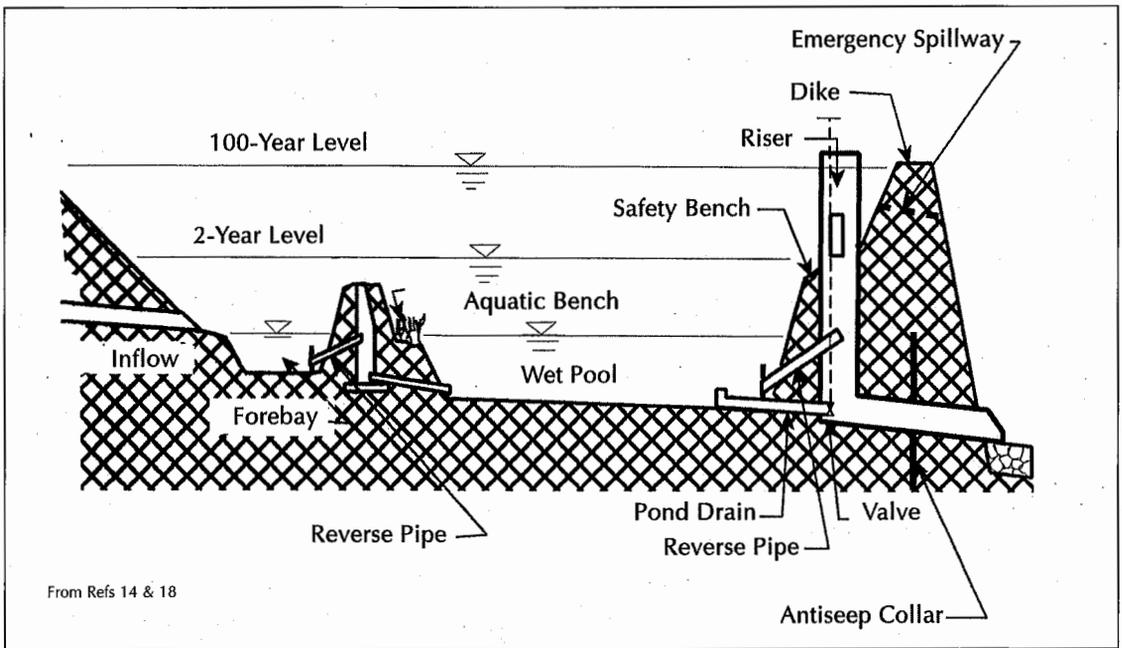


FIGURE 6. Extended dry pond modification for winter operation. Inlets and outlets should be submerged to reduce freezing problems.

Because salt is a conservative pollutant, providing sufficient dilution, providing storage during times when dilution is not available and, in coastal areas, providing a conveyance to the sea can effectively mitigate excess sodium and salinity loads. Use of alternate biodegradable organic deicing compounds and deicing mixtures is a feasible alternative in vulnerable watersheds provided that their adverse environmental consequences (oxygen demand and nutrient content) are considered and the loads do not exceed the loading capacity of the receiving water bodies. Use of liquid mixtures that do not contain cyanide anticaking compounds is preferable. Excessive salinity and cyanides from salt and dissolved oxygen depletion by alternate organic deicers are often issues of the total maximum daily load (TMDL) process specified and are required by the Clean Water Act issues and should be considered as such by the responsible pollution control agencies.

Conclusion

It is a well-established fact that urban and highway snowmelt is polluted and could adversely affect the integrity of receiving

waters. The magnitude of pollution and its character is different from off-winter stormwater runoff. Some water quality parameters that are very significant during winter snowmelt and must be addressed (e.g., cyanide and dissolved metals) are often insignificant in off-winter stormwater from the same locality. In some urban streams, cyanide and metal pollution during winter may exceed established water quality standards. Pollution control agencies may respond to this not easily traceable problem by applying more stringent point source controls instead of focusing on the diffuse sources — i.e., snowmelt.

Managing snowmelt pollution is often mandated by the stormwater permits for northern municipalities. For example, the city of Madison permit requires the city to implement a deicing salt reduction program. Unfortunately, effective tools to help agencies to consider the environmental consequences of deicing operations are currently not available. In many cases, a successful winter pollution abatement program will require judicious and efficient application of deicing chemicals with application rates determined by comput-

erized real-time control incorporated in regional RWISs. Less environmentally damaging chemicals should be selected and used, especially in environmentally sensitive areas. Reducing winter pollution from urban areas and highways requires the cooperation of local and regional pollution abatement agencies, transportation departments and airport authorities. The management of snowmelt pollution must be included in the watershed management plans and in vulnerable watersheds included in TMDL plans.

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NOTE — *The marketing name for the agriculturally derived compound is Ice Ban.*



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