Road salts, human safety, and the rising salinity of our fresh waters

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In the US, 70% of the population lives in regions that experience snow and ice. Road deicing salts reduce vehicular accident rates in these regions by >78% but have led to dramatic increases in freshwater salinity. To seek environmental management and policy solutions, we ask: (1) how much salt is used and where is it applied, (2) do current agency thresholds protect freshwater biota, (3) are deicing salts affecting our water supplies, and (4) how can we curb salinization from deicing salts? Use of deicing salts has tripled over the past 45 years and blankets much of the US. There is an urgent need to reassess inadequate thresholds to protect freshwater biota and our drinking water supplies. Given the lack of ecologically friendly and cost-effective alternatives, broad-scale adoption of best management practices is necessary to curb the increasing salinization of freshwater ecosystems resulting from the use of deicing salts.

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In the US, regions impacted by snow and ice contain 70% of the roads and 70% of the population (USDOT 2017). Road deicing salts are applied in these cold regions to protect the traveling public because they reduce vehicular accident rates by 78–87% (Kuemmel and Hanbali 1992; Mullaney *et al*. 2009; Usman *et al*. 2010). However, widespread application of these salts has triggered substantial increases in freshwater salinity, threatening not only the biodiversity and functioning of freshwater ecosystems (Hintz and Relyea 2019) but drinking water supplies and human health as well (Kaushal *et al*. 2005; Kelly *et al*. 2018).

In a nutshell:

- The use of road deicing salts is triggering a massive increase in freshwater salinity in cold regions worldwide
- Threshold concentrations to protect freshwater biota are commonly surpassed, suggesting an urgent need to reassess these thresholds
- There is also widespread contamination of our drinking water supplies
- Deicing salts trigger the mobilization of harmful substances such as radon, mercury, and lead, further threatening freshwater biota and drinking water supplies
- The lack of ecologically friendly, cost-effective alternatives to deicing salts requires immediate adoption of best management practices to reduce the salinization of freshwater ecosystems

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Inorganic salts like sodium chloride (NaCl), calcium chloride ($CaCl_2$), and magnesium chloride ($MgCl_2$) are the most commonly used deicing salts (Evans and Frick 2001). Salt use for road deicing began in the US around 1938, in New Hampshire and Detroit, Michigan; since the mid-1970s, the use of NaCl "rock salt" for deicing has tripled (Figure 1). Early warnings of road salt contamination among freshwater ecosystems and the associated impacts began to emerge in the 1970s; for example, in an article published in *Science*, Huling and Hollocher (1972) reported contamination of groundwater sources (used as drinking water supplies) by deicing salts. That same year, also in *Science*, Feick *et al*. (1972) showed that deicing salts triggered the release of mercury (Hg) in contaminated sediments. However, little progress has been made since the 1970s to generate proactive- or reactive-environmental policy to address road salt contamination of freshwater systems. Such policy solutions can be difficult to craft. Transportation departments are often required by law to provide safe traveling conditions during the winter, and as such balancing the need to minimize accidents while conserving freshwater resources requires careful policies and management practices. Although there are rock salt alternatives, such as potassium- and calcium-magnesium acetate, agricultural biproducts (eg beet juice), and abrasives (eg sand), these can trigger other problems, such as deposition in freshwater habitats (eg sand), introduction of nutrient subsidies, and changes in food webs (Schuler *et al*. 2017). Alternatives to chloride-based deicers can also be cost-prohibitive (Kelting and Laxson 2010).

Before we can effectively engage in environmental policy solutions, we must understand the magnitude of the road salt issue and identify and adopt best management practices (BMPs). We currently lack a full understanding of several important questions: (1) how much salt is used and where is it applied? (2) Do agency thresholds protect freshwater biota? (3) Are deicing salts affecting our water supplies? and

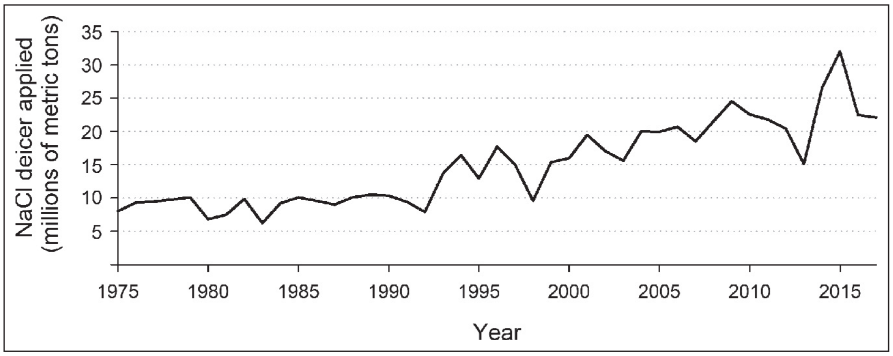

Figure 1. Metric tons of sodium chloride (NaCl) used for deicing purposes in the US from 1975–2017. Graph redrawn from Kelly *et al.* (2019); data from Kelly and Matos (2014).

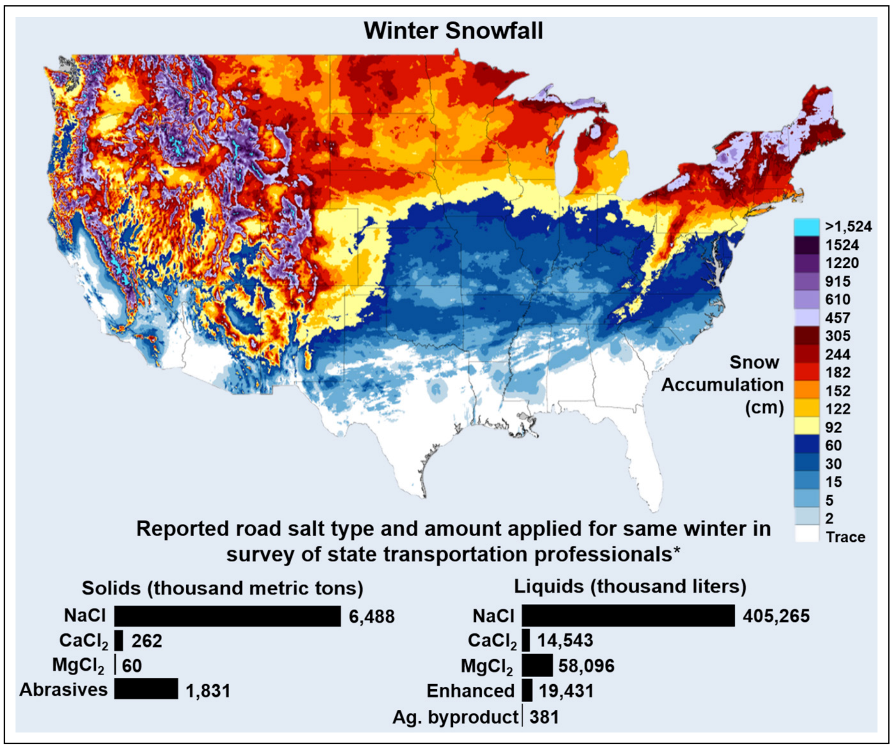

Figure 2. Snowfall in the contiguous US during the 2016–2017 winter season (top) indicating the spatial extent and need for deicing practices, and the relative amount and type of road salts applied for the 2016–2017 winter season (bottom) from 36 state transportation departments in a survey conducted by the Clear Roads organization (http://clearroads.org/winter-maintenance-survey). Snowfall images and data provided by National Oceanic and Atmospheric Administration (https://www.ncdc.noaa.gov/snow-and-ice). Enhanced brines ("Enhanced") are typically a combination of the inorganic salts of sodium chloride, calcium chloride, or magnesium chloride. *The total actual amount of road salts, abrasives, and byproducts applied will be higher than the relative values provided here due to unreported use and the lack of information from smaller operations (eg private contractors, local municipalities).

(4) How can we curb salinization from deicing salts? We address these questions with the goal of facilitating the development of policies and management actions to protect fresh waters.

How much road salt is currently used and where is it applied?

The amount, type, and rate at which road deicers are applied varies regionally with winter weather patterns. US National Oceanic and Atmospheric Administration (NOAA) data show that snowfall for the 2016–2017 winter season covered most of the contiguous US (Figure 2), requiring the use of deicing salts to maintain road safety. Many interstate highway systems (eg I-70, I-80, I-90) in these regions are heavily treated due to the economic costs of road closures.

A survey by Clear Roads – an organization of transportation professionals and researchers – examined the types and amounts of materials used by US state transportation agencies to keep roads safe and operational. In the survey year matching snowfall patterns in Figure 2, 36 states reported use of various materials (Figure 3; Clear Roads 2017). According to the survey, the most common deicers were the inorganic salts NaCl, $MgCl_2$, and $CaCl_2$ (Figure 2). Rock salt (NaCl) and abrasives were applied in the greatest amounts, while the most commonly applied liquid or brine was NaCl followed by $MgCl_2$. States in milder climates use substantial amounts of deicers because of economically important transportation routes in mountainous regions. A caveat to the Clear Roads data is that they do not include salt use by every state, local municipality, or private contractors that apply salt to driveways, sidewalks, and parking lots, and therefore the total amount of deicing materials being applied in the US is much higher than reported in Figures 2 and 3 because of untracked or unreported sources. Nevertheless, the Clear Roads survey provides a benchmark to understand relative trends in the amount of deicer materials applied over space and time.

Terrain, human population density, road density, and road usage affect the demand for deicing materials, and where and how they are applied (Kelting and Laxson 2010; Kelting *et al.* 2012). Annual application rates of deicing salts in many US states, Canada, and Sweden range from 12–75 metric tons/km of two-lane highway, equivalent to 1.3–8.3 kg/m^2 (Evans and Frick 2001; Löfgren 2001; Kelting and Laxson 2010). In southern Ontario, Quebec, and Alberta (Canada), application rates can be as high as 11 kg/m^2 (Evans and Frick 2001). In New York State, the average application rate of deicing salts is about 13 metric tons/lane km (Kelting and Laxson

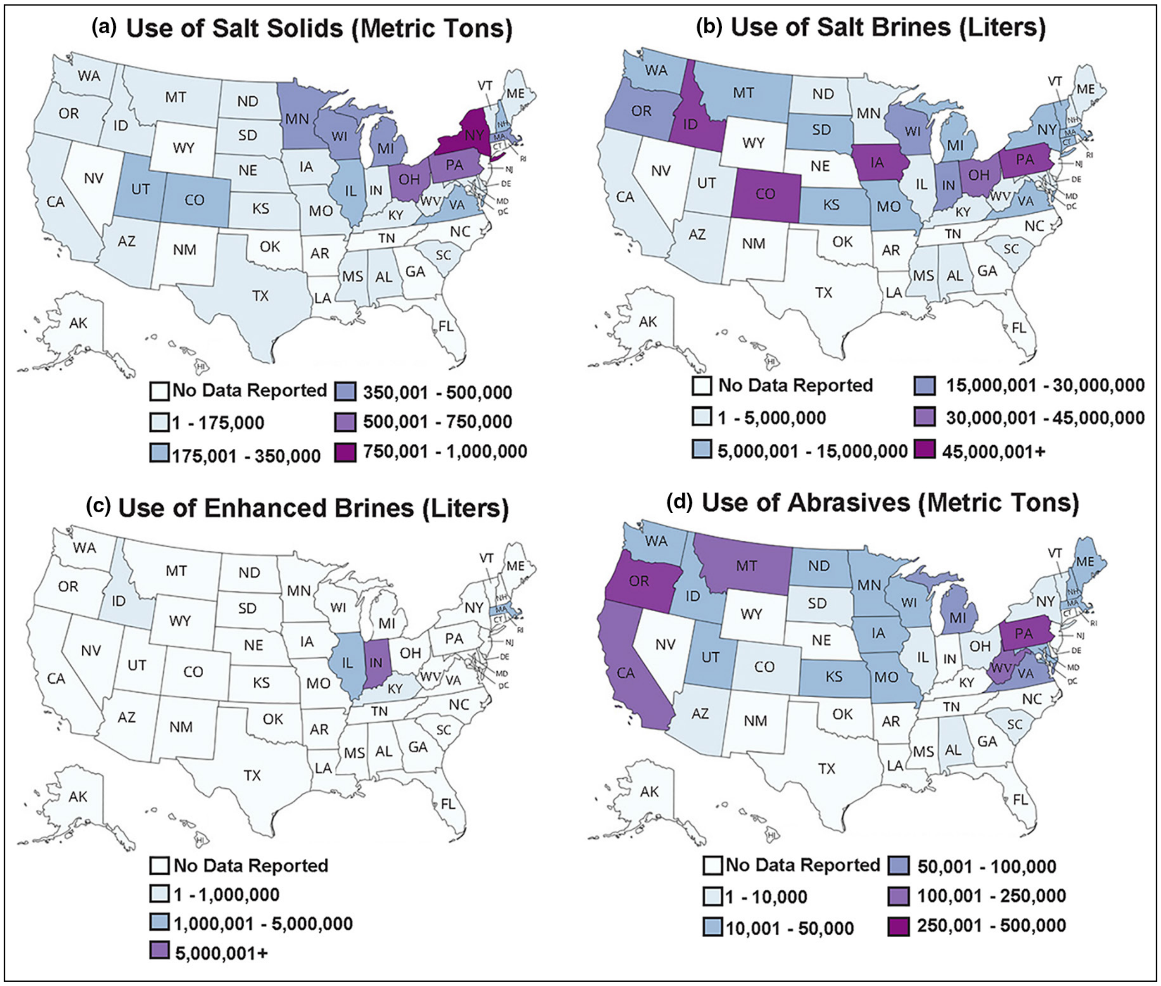

Figure 3. Amount of winter road maintenance materials applied in the winter of 2016–2017 in 36 US states. Values reported are from state transportation agencies (Clear Roads 2017) and include the use of (a) salt solids (inorganic salts; metric tons), (b) salt brines (L), (c) enhanced brines (L), and (d) abrasives (eg sand; metric tons). The amount of salt solids and brines (or blend) includes combined values for the three primary inorganic salts (sodium chloride [NaCl], calcium chloride [$CaCl_2$], and magnesium chloride [$MgCl_2$]) used in deicing operations. Enhanced brines are typically a combination of the inorganic salts. Figure design by R Carter.

2010). Some studies report total road salt usage per unit area. In the 21,030 km^2 Twin Cities Metropolitan Area (Minnesota), 316,607 metric tons (15 metric ton/km^2) of road salt were applied annually (Novotny *et al*. 2007). During the 2012–2013 winter season, in an area of 88 km^2 within the city of Moscow (Russia), 450,000 metric tons (5113 metric tons/km^2) of deicing salts were applied, despite a 30,000–40,000 metric ton limit set to protect ecosystems throughout Moscow (Nikiforova *et al*. 2014). Although highly variable, one pattern is clear: the amount of deicing salt applied per unit area in cold regions is substantial.

Are current agency thresholds enough to protect freshwater biota?

Chloride (Cl^-) concentration is a good signal of deicing salt contamination because it is the anion of the major inorganic deicing salts, is not biologically transformed, and typically stays in solution (ie Cl^- is a conservative tracer; Hayashi *et al*. 1998). Other measures of salt contamination include conductivity and salinity. Although all of these measures have been used successfully to study road salt pollution, here we focus primarily on Cl^- concentration.

Chronic and acute Cl^- concentrations are used to protect freshwater biota by the US Environmental Protection Agency (EPA). Chloride was used by the EPA to set these thresholds because elevated concentrations reveal contamination from anthropogenic sources, such as deicing salts, runoff and discharge from municipal sources, and industrial waste (EPA 1988). A chronic effect is generally defined as "an adverse effect on any living organism in which symptoms develop slowly over a long period (eg days) of time or recur frequently" (EPA 2011). An acute effect is defined as "an adverse effect on any living organism in which severe symptoms develop rapidly (eg hours) and often subside after the exposure stops" (EPA 2011). The EPA has established chronic and acute thresholds of 230 mg Cl^-/L and 860 mg Cl^-/L, respectively, to protect freshwater biota (EPA 1988). Thresholds in other countries, such as Canada, are lower, at 120 mg Cl^-/L for the chronic threshold and 640 mg Cl^-/L for the acute threshold (CCME 2011). The EPA Cl^- thresholds were developed through a review of published studies and calculated according to the *Guidelines for Deriving Numerical National Water Quality Criteria for the Protection of Aquatic Organisms* (EPA 1985, 1988). The original derivation of these Cl^- thresholds only relied on data from studies using NaCl because not enough information was available on other chloride-based salts when these thresholds were derived in 1988 (EPA 1988).

Concentrations among freshwater ecosystems

Where used, deicing salts are the largest anthropogenic contributor of Cl^- to freshwater systems compared to other sources (eg Mueller and Gaechter 2012; Hill and Sadowski 2016). To determine the range of Cl^- concentrations (mg Cl^-/L) in lakes, streams and rivers, and wetlands, we surveyed the scientific literature and assessed the EPA's National Aquatic Resource Surveys Database (NARSD; EPA 2012). We used two datasets from the NARSD. For lakes, we used the 2012 National Lakes Assessment (NLA). Lakes in this dataset excluded naturally brackish lakes and were surveyed only if they were a natural or man-made freshwater lake, pond, or reservoir >1 ha in areal extent, >1 m deep, and with a minimum open-water surface area >0.1 ha (EPA 2012). We sorted the data by the unique site visit identification number and generated a histogram to identify the frequency of freshwater lakes for a given Cl^- concentration with increments every 20 mg Cl^-/L. For rivers and streams, we used the EPA's 2008–2009 Rivers and Streams Water Chemistry dataset, from which we sorted river and stream data by the unique site ID number and used the average Cl^- concentration if a site was visited more than once. Finally, we compared Cl^- concentrations for lakes and streams/rivers with known unimpacted or historical (ie pre-road salt contamination) Cl^- concentrations published in the literature. This allowed us to identify how road salts and other anthropogenic sources of Cl^- have increased in these systems relative to Cl^- thresholds set by the US and Canada. Most studies report conductivity rather than Cl^- concentration in wetlands, making it difficult to distinguish Cl^- contamination from other ions in wetlands; we therefore relied solely on the peer-reviewed literature to identify Cl^- concentrations from deicing salts in wetlands.

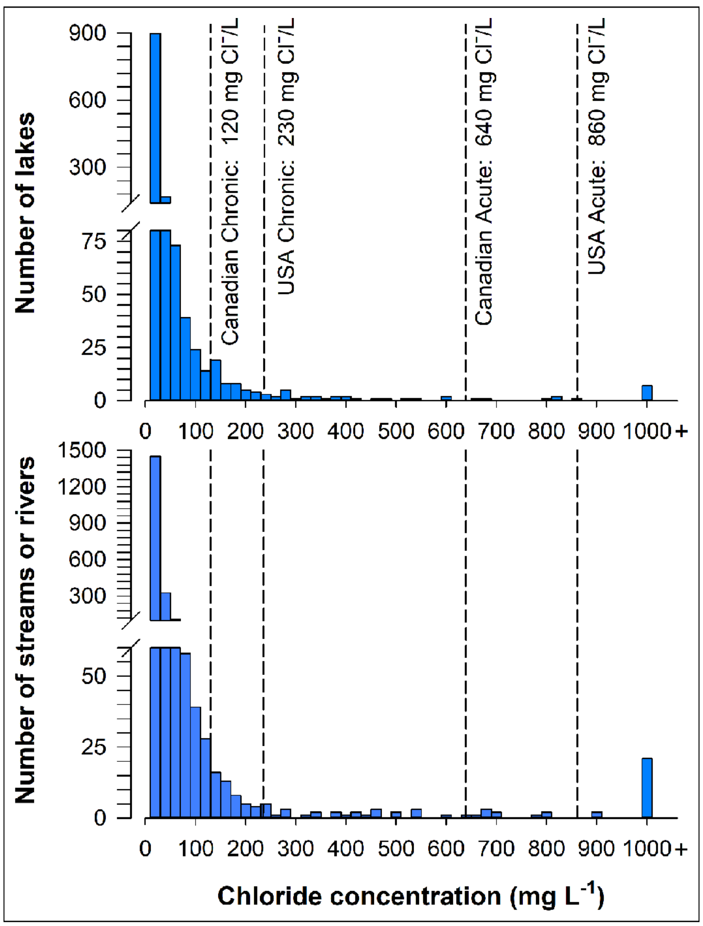

Figure 4. Chloride concentrations reported for lakes (top) and streams (bottom) from the US Environmental Protection Agency's National Aquatic Resource Surveys (NARS) and the scientific literature. Although the chronic and acute thresholds presented here (dashed vertical lines) are established by the US and Canadian governments, new research suggests that negative effects on zooplankton could occur between 5 and 40 mg Cl^-/L in soft-water (ie low water hardness) and low-nutrient lakes (Arnott *et al.* 2020).

Lakes

Inland freshwater lakes have historically low Cl^- concentrations, typically <10 mg Cl^-/L (Evans and Frick 2001; Kelting *et al.* 2012). According to the 2012 EPA NLA and the scientific literature, although most freshwater lakes in the US range from 0 to 20 Cl^-/L, numerous lakes are at concentrations >20 Cl^-/L (Figure 4; Dugan *et al.* 2017, 2020). A survey of 138 lake watersheds revealed that lakes with no paved roads within their catchment exhibit concentrations <5 mg Cl^-/L, whereas 35% of lakes with paved roads exhibit Cl^- concentrations seven times higher (up to 40 mg Cl^-/L; Kelting *et al.* 2012). In a large, deep oligotrophic lake in New York State's Adirondack Park, road salt concentrations have tripled over a 37-year period from the use of deicing salts (from 6 mg Cl^-/L to 18 mg Cl^-/L; Hintz *et al.* 2020). Salt concentrations in many lakes in the US Midwest exceed those of northeastern lakes, with high concentrations ranging from 217 to 445 mg Cl^-/L (eg Bridgeman *et al.* 2000; MacLeod *et al.* 2011; Sibert *et al.* 2015). A small number of lakes (mostly urban or artificial) can approach or exceed 1000 mg Cl^-/L at some point during the year (eg Cherkauer and Ostenso 1976; Novotny *et al.* 2008). Despite their large volumes, even the largest lakes have experienced Cl^- contamination from deicing salts. Historical Cl^- concentrations of the North American Great Lakes were <2.5 mg Cl^-/L, but for Lake Erie and Lake Ontario Cl^- concentrations have exhibited an eight- to tenfold increase since the 1800s due in part to road salt use (Chapra *et al*. 2009). Similarly, road deicers were found to be responsible for over half of the twofold increase in Cl^- concentration in Lake Constance, one of Europe's largest freshwater lakes (Mueller and Gaechter 2012). Dugan *et al*. (2017) has estimated that many freshwater lakes will exceed the EPA threshold of 230 mg Cl^-/L in the next 50 years.

Streams

The number of salinized streams currently approaching biological thresholds is particularly troubling (Figure 4). Over forty years ago, one study showed stream water concentrations reached as high as 1770 mg Cl^-/L (Crowther and Hynes 1977), while recent studies show urban streams with concentrations of 4700–7730 mg Cl^-/L (Kaushal *et al*. 2005; Corsi *et al*. 2010), more than 20–30 times higher than the EPA chronic threshold. Corsi *et al*. (2010) found that 55% of 168 monitoring locations in 13 northern US cities exhibited Cl^- concentrations above the EPA chronic threshold and 25% were above the acute threshold at some point between November and April.

Contaminated streams maintain high salt concentrations during the warmer months (Kelly *et al*. 2008). For instance, chloride concentrations in streams around Baltimore, Maryland, remain 100 times higher than forested reference streams through the summer and fall because of hyporheic and groundwater release (Kaushal *et al*. 2005). In fact, salt concentrations can remain just as high in summer as winter (45–50 mg Cl^-/L; Kelly *et al*. 2008). Streams and rivers also experience intense pulse and press dynamics, with pulse events leading to concentrations of 4528 mg Cl^-/L in urban streams during the winter from baseline concentrations of 101 mg Cl^-/L in the fall (Kaushal *et al*. 2005).

Wetlands

Baseline Cl^- concentrations in forested wetlands are typically <3 mg Cl^-/L (Hill and Sadowski 2016) but can be as high as 12 mg Cl^-/L (Richburg *et al*. 2001). In salt-contaminated wetlands, Cl^- concentrations can be as high as 3950 mg Cl^-/L but are typically <1000 mg Cl^-/L (Evans and Frick 2001). The elevated conductivities observed by Van Meter *et al*. (2011) are likely due to road salt, indicating that Cl^- levels in stormwater retention ponds can reach 4500–10,312 mg Cl^-/L. Concentrations as high as 13,500 mg Cl^-/L have been observed near salt storage facilities (Ohno 1990). As with lakes, salts are not flushed out of wetlands quickly (Hayashi *et al*. 1998), and therefore high Cl^- concentrations persist long after snowmelt (Sriyaraj and Shutes 2001). Water evaporation in wetlands during summer can further increase salt concentrations due to reduced water volume (Collins and Russell 2009), exposing biota to high salt concentrations year-round.

Current thresholds are clearly not enough

Current Cl^- thresholds are insufficient to protect freshwater biota. Chloride concentrations among fresh waters exceed established thresholds in the US and Canada. In addition, it is now recognized that $CaCl_2$ and $MgCl_2$ sources of Cl^- can be more toxic to some freshwater organisms than NaCl (Mount *et al*. 2016). The impacts of deicing salts can be sublethal or lethal at current thresholds (Hintz *et al*. 2017; Hintz and Relyea 2017), and recent research suggests that negative effects can occur at levels far below these thresholds. For example, Arnott *et al*. (2020) demonstrated that zooplankton may be negatively affected by Cl^- concentrations as low as 5–40 mg Cl^-/L. Arnott *et al*. (2020) suggested water chemistry such as a low calcium concentration in Canadian Shield lakes may be responsible for the low Cl^- concentrations at which zooplankton elicit a negative response. These results highlight regional context-dependence in the response of freshwater organisms, which needs to be reflected in proactive, ion-specific thresholds to address road salt pollution (Schuler *et al*. 2019). In addition, freshwater ecosystems are often contaminated with a cocktail of contaminants (Relyea 2009); road salts not only add to but also influence the concentration and mobilization of a wide range of contaminants (Kaushal *et al*. 2019, 2020). While further research is needed to better understand the impacts of road salts at the organismal, community, and ecosystem levels (Hintz and Relyea 2019), there is also an urgent need to understand how freshwater organisms will respond to novel chemical cocktails generated from road salt salinization (Kaushal *et al*. 2019). Finally, we must be mindful that long-term data collected over a single season (eg only in winter or only in spring) may result in underestimations of the saline concentrations that freshwater organisms are exposed to because of seasonal pulse/press dynamics – an important consideration for successful policy and management approaches.

How are road salts affecting drinking water supplies?

Another concern surrounding deicing salts is the unintended contamination of human drinking water sources. The EPA recommends a threshold concentration of 20 mg Na^+/L, a level based on individuals with Na^+-restricted diets (EPA 2003). Under the EPA's secondary drinking water regulations, the threshold concentration for Cl^- is 250 mg/L (EPA 2018). Yet numerous case studies demonstrate contamination of drinking water exceeding thresholds for human consumption. Huling and Hollacher (1972) estimated that steady-state concentrations in private wells in Massachusetts in the 1970s were 160 mg Na^+/L and 100 mg Cl^-/L. We have had more than 40 years of salt application since then; one recent study in New York State estimated that 24% of private wells were contaminated with deicing salt and 70% of survey participants stopped using their well water because of safety concerns (Pieper *et al.* 2018). Similar cases of well contamination were reported in Wisconsin, with well-water concentrations exceeding 400 mg Cl^-/L (Rayne *et al.* 2019). High concentrations of deicing salt typically occur in wells located near roads in lower elevations or downhill from road networks (Kelly *et al.* 2018).

Of particular concern is that deicing salts mobilize multiple harmful substances. Feick *et al.* (1972) showed that NaCl and $CaCl_2$ increased the amount of Hg released from contaminated sediments by 2–5 orders of magnitude. Release of Hg from sediments into surface waters is alarming because Hg is highly toxic to humans and freshwater organisms (Wentz *et al.* 2014). Moreover, the most common deicing salt (NaCl) increases aqueous concentrations of cadmium (Cd), copper (Cu), and zinc (Zn) through ion exchange, reduces pH, and triggers the formation of Cl^- complexes in roadside soils, threatening drinking water supplies (Backstrom *et al.* 2004). Mobilization of heavy metals will increase both the rate they move across and the depth they penetrate leachate zones (Schuler and Relyea 2018), which has the potential to increase their concentration throughout well-water fields. In groundwater, Na^+ mobilizes dissolved radium (Ra), which can lead to increased radon gas (Rn) flux from water tables above the EPA action contaminant level of 4 pCi/L (McNaboe *et al.* 2017). Many homes have Rn-mitigation systems to control naturally occurring concentrations of Rn gas. McNaboe *et al.* (2017) concluded contamination of groundwater by NaCl will lead to greater exposure to Ra and Rn – radioactive and carcinogenic elements.

There is also serious concern for drinking water supplies surrounding Cl^--induced lead (Pb) mobilization. The Cl^- ion in many inorganic salts triggers the release and transport of Pb from roadside soils, contaminating surface waters (Backstrom *et al.* 2004; Bacon *et al.* 2006). Using Cl^--contaminated water for drinking water can be dangerous because Cl^- results in the dezincification of water plumbing and galvanic corrosion, which increases the thinning of pipe walls and metal leaching (Pieper *et al.* 2018). This process likely led to the release of Pb from water distribution pipes contributing to the drinking water crisis in Flint, Michigan, in 2014 (Lin *et al.* 2016). The high concentration of Cl^- in water withdrawn from the Flint River was due to its treatment with ferric chloride to address trihalomethanes, but the river water also registered 85 mg Cl^-/L (Dingle 2016; Torrice 2016), an unnaturally high level for a river in the Midwest US (Hintz and Relyea 2019). While identifying the exact source of Cl^- when multiple sources exist can be difficult, the regional climate necessitates heavy deicing operations, a likely source of Cl^- to the Flint River (Dingle 2016). Many Flint-area residents, particularly children, will experience long-term physical and neurological impacts due to the toxic effects of Pb.

Are there solutions?

Ending the use of deicing salts seems a simple enough solution, but this may not be currently feasible. At present, there are no ecologically friendly and few cost-effective alternatives to deicing salts (Schuler *et al.* 2017). Currently, adoption of BMPs across cold regions can contribute to protecting our freshwater resources (Figure 5).

Proper storage is essential to prevent contamination of surrounding fresh waters. In 2014, 3–75% of salt storage facilities were storing salt on permeable ground with inadequate to no covering (Fay *et al.* 2015). Although a costly option, salt storage structures should be permanent, four-sided structures with an impervious concrete base (Fay *et al.* 2015). This will prevent the greatest economic loss of material and is the best option to protect surrounding waters. Cheaper options include any roof type with a three-sided building with impervious concrete bases or any structure to cover the salt pile to prevent unintentional loss (Fay *et al.* 2015). For liquid material, secondary containment structures and well-maintained infrastructure (hoses, fittings, impact reduction structures) are needed to prevent leaks and spillage.

Anti-icing and pre-wetting of impervious surfaces improve the efficiency of using deicing salts. Anti-icing is the application of liquids, such as salt brines, to the road surfaces prior to winter storm events, which prevents ice from bonding to surfaces and aids removal operations. Anti-icing can reduce salt needed in a reactive scenario by 75% (Nixon and

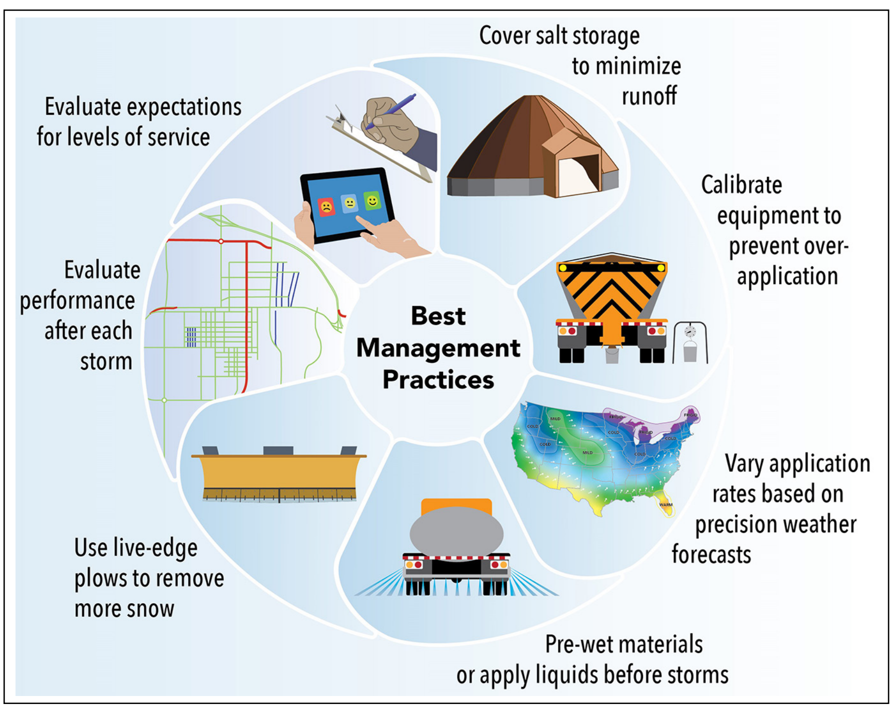

Figure 5. Best management practices in need of broad-scale adoption to curb the salinization of freshwater ecosystems from the use of road deicing salts. Figure design by N Hetherington.

DeVries 2015). Pre-wetting adds a liquid to a solid, such as salt brine to solid salts prior to application; this can reduce the amount of salt transported into road margins, where it is not needed, by 26%.

Variable application rates and equipment calibration can be adopted with little monetary investment and use event-specific information, such as pavement surface temperature, storm intensity and duration, and route use information, to apply the proper amount needed in the proper location (Fay *et al*. 2015; Nixon and DeVries 2015). Storm-specific strategies prevent salt overapplication and can reduce seasonal salt need by 50% (Nixon and DeVries 2015), and may represent one of the most important BMPs (Fay *et al*. 2013, 2015; Nixon and DeVries 2015). Calibrating salt spreaders or sprayer equipment at the beginning of and during winter, and when switching between deicer types, are also essential for avoiding overapplication (Fay *et al*. 2015).

Using live-edge snowplows reduces the need for road salt by enhancing the efficiency of snow and ice removal. While conventional plows have a single fixed edge, live-edge plows are composed of multiple smaller plows on springs that better conform to the convex shape of most roads. By conforming to the surface, live-edge plows remove more snow and ice from the road than static-edge plows, reducing the need for deicing salt.

Evaluating performance of the deicing strategy after each storm is also critical (Fay *et al*. 2015). This can be done in a formal debriefing or informally. Post-storm performance assessment provides information on whether the prescribed treatment was appropriate for the weather system. Performance evaluation allows applicators to ask: what did and did not work? How should the prescribed deicing treatment be modified? Was the weather forecast accurate? Was the team prepared? Was the expected level of service met? Ultimately, post-storm evaluation integrated with other BMPs will facilitate a reduction of salt loading into surface and ground waters.

Public expectation also influences how much deicing salt is applied. Level of service (LOS) is the condition a roadway will be maintained, and can range from closed roads to bare pavement (Nixon and DeVries 2015). Economic drivers and societal LOS expectations establish how much salt is needed to generate bare- or almost-bare-pavement conditions. The public will need to evaluate the prescribed and expected LOS and consider that our expectations during the winter may come at the cost of contaminating freshwater ecosystems.

Conclusion

Salinity levels in our lakes, streams, rivers, and wetlands are rising from the use of deicing salts. Adding to the concern about the ecological impacts of road salts is the contamination of our drinking water supplies and mobilization of harmful substances such as Rn, Hg, and Pb. High salinity presents its own unique health concerns for humans and freshwater organisms, but many heavy metals are toxic at very low concentrations. Given that road deicers reduce vehicular accident rates by more than 78%, how do we strike a balance between human safety and mitigating the negative environmental and health impacts of road salts? While this is a difficult question to answer, the issue of freshwater salinization from road salts nevertheless requires immediate attention from policy makers and environmental managers. The BMPs summarized here likely represent, at present, the most effective means of protecting fresh waters from the harmful effects of road deicing salts.

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FrontiersEcoPics

Sex on the beach

The reproductive behavior of the pufferfish *Takifugu alboplumbeus* (previously *T niphobles*), which lives in the northwest Pacific Ocean, is special for several reasons. From mid-May to mid-July, concentrations of these fish can be observed at a few sites along the coast of Japan. These pictures were taken a few meters from the shoreline at Arai Beach (Miura, Japan), near the Misaki Marine Biological Station. One or two days after either the full moon or the new moon, and coinciding with the timing of highest tide, hundreds of *T alboplumbeus* males position themselves near the shore and await the arrival of mature females (the proportion can be around 20 males per female). When a female arrives, she swims into the shallows, propels herself out of the water using the help of waves, and temporarily lays on the exposed sand. Several males follow each female out of the water. The female then spawns while the males fertilize the eggs. Once complete, the fish return to the sea. During highly active periods, we have seen more than 100 pufferfish over the sand on a single occasion. Evolutive reasons could explain the choice of specific places along the coast, and the lunar phases and tides might synchronize the simultaneous arrival of males and females, but why have sex out of the water, if you are a fish?

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