Salting The Earth

The Problem

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Anyone who has spent a winter in the Northern part of the United States has likely experienced crunching down on swaths of white as they walk or drive. More often than not, it's not ice or snow, but road salt- most commonly in the form of sodium chloride (NaCl). Salting to reduce ice on roadways and sidewalks has been common practice in the United States since 1938, when New Hampshire began experimenting with this technique (Kelly *et al.*, 2010). The dependance on road salt has grown significantly in the United States from 164,000 tons spread in 1940 to an average of 24 million tons today (K.B.U. Today, 2019). Road salt is not exclusively used by state and federal governmental bodies, it is also used by businesses and private citizens to prevent slip and fall injuries on private property across the US (Commonwealth of Massachusetts, 2024). In addition, various states have laws that require roads to be clear for travel at all times, which places a high salt burden on these areas during the winter months. For example, in New York state, the state government is required to return roads to “bare pavement as quickly as possible” (*Winter Maintenance Program,* no date). These provisions place considerable pressures onto highway managers, making it difficult to reduce the amount of salt they apply.

With the pervasive use of road salt not just within the United States, but other snow-prone areas across the globe, it is crucial to understand how the large-scale release of these materials could impact our world. It is an easy problem to overlook, as it has become a normalized for people in these areas and is forgotten as quickly as the snow melts. The application of sodium chloride can have negative repercussions on various levels of biological organization- from individual people and animals to the ecosystem- and understanding these effects is crucial to underscore the importance of reducing salt dependence. There are already techniques and alternatives used in various areas with some success, and a whole body of research on mitigation techniques or alternatives to keep roads safe in winter.

The Effects

With road salt being used in great volumes extensively across the entire country, its impact on human health and the environment is a subject of concern for many interest groups and research organizations here in the United States. One such organization t is the Cary Institute, a private non-profit research institution located in New York state that has been researching the environmental effects of road salt applications on freshwater ecosystems and the surrounding environment for several years. A major concern is that road salt does not stay in the areas it was applied, but rather can bounce off the pavement or wash away with snowmelt and rain. Once dissolved, it can intrude into groundwater and other freshwater ecosystems that various plants, animals, and even humans depend on. This salt is very difficult to remove once it gets into the watershed, and can also build up over time. The Cary Institute has found that salt "is retained…to a much greater extent than was previously realized. Concentrations have been increasing over time, even in watersheds without new roads…summertime levels can be as high as in the winter" (*Understanding the legacy of road salt in the environment*, 2024). In order to understand the broad scale effects of salt application, it is crucial to understand what the concern is with excess salts in the environment.

When road salt is applied, a large avenue for the unintended release into the environment occurs because the salt can bounce and scatter off of the road or run off due to rain or the melting of snow and ice. This causes the salts to be dissolved, which increases the salinity of the runoff that could percolate into groundwater and other water sources. Although water and chloride themselves are naturally present in water, the release of these additional salts can cause the salinity to exceed natural levels. Additionally, the chloride can also cause the pH of the water to lower resulting in corrosive effects, which is especially concerning as older pipes may have components of copper or lead that could contaminate the water and harm the people or animals drinking from these sources (*Road salt, corrosivity and lead*, no date).

Natural Communities:

Some of the most vulnerable communities are those that are near the source of excess salts, especially those directly next to roadsides in areas that experience snow.

Animals

Animals are specifically at risk of negative effects from excess road salts, as they depend on their local environment for food and water. A common occurrence is road salts contaminating water pools as the runoff leaches into freshwater systems nearby or accumulates in pools near the roadside. The animals that depend on these water sources are then exposed to unnaturally high levels of salts, which can cause life threatening conditions.

Some of the most at risk groups of animals are amphibians, as they are more sensitive to changes in environmental conditions than other species due to their ability to breathe through their skin. This exposes them more directly to environmental factors that could potentially make them sick, such as disease, radiation, and pollution (U.S. Geological Survey, 2016). Additionally, amphibians are often considered “indicator species” for the health of ecosystems, and the easily apparent negative impacts of salinity on amphibians suggests concern regarding road salt salinization may be warranted.

Various studies on the effects of road salt on adult and larval amphibians including frogs, toads, and salamanders have been conducted with evidence suggesting population level issues for these species. Survival of frogs and salamanders decreased when exposed to salt, with frogs having higher mortality than salamanders. The larvae of these species are especially vulnerable, as road salt has been found to delay hatching (Ocampo, Chuirazzi & Takahashi, 2022), reduce the size of frog larvae with increasing salinity (Tornabene, Breuner, & Hossack, 2020), and alter sex ratios when tadpoles are exposed to intermediate levels of salt concentrations (Leggett, Borrelli, Jones, & Relyea, 2020). Additionally, the effects of chloride specifically in amphibians was also explored, and it was discovered that spotted salamanders and wood frogs wouldn't occupy ponds with high levels of chlorides (Collins & Russell, 2009).

All of these findings suggest that population structure and distribution of amphibians can be drastically altered with the addition of road salt to their environments. For the safety and continued survival of these particularly sensitive species, best management plans should account for the consequences road salt usage may have on their habitats.

Beyond amphibians, other animals are also at risk. Various species of birds, especially those that depend on vegetation or grains for food, have been documented to be attracted to salt. The main school of thought on this attraction is that these birds require additional salt that is otherwise difficult for them to get in their diet. However, a major concern is that birds are often hit by cars when they land on roads covered in salt to get this otherwise limiting nutrient. This relationship was further explored in a meta analysis by Mineau and Brownlee in 2005 with an emphasis on winter finches, in which they found that salt toxicity may contribute to the death of birds by the roadside. This is because terrestrial birds lack adaptations that marine birds and other vertebrates have to reduce internal excess salt, and therefore these birds must increase their water intake to reduce their internal salinity. Unfortunately, road salt usage coincides with the time of year that the water sources for small birds are often frozen over, so they are unable to increase their water consumption to reduce their internal salinity. Additionally, the ponds they do have access to are often by roadsides and have higher salinity than natural pools. These factors increases their risk of mortality due to of salt toxicity (Mineau, Brownlee, 2005).

Birds are not the only organisms that are killed when they attempt to use salt pools made readily available on road sides during the winter months, as moose have also been documented utilizing these pools during the winter. Moose populations have been in decline across various parts of the North Americas (Timmermann & Rodgers, 2017), as this species faces various anthropogenic (human caused) and natural stressors including hunting, predation, and pathogens/parasites (Murray et al. 2006). A study conducted in 2009 modeled the effects of reducing the presence of roadside salt pools in the Laurentides Wildlife Reserve on the occurrence of moose-vehicle collisions, and found that removing all of the salt ponds resulted in a 49% reduction of moose vehicle collisions compared to only 16% when only two thirds of the pools were removed (Grosman et al., 2009). Although this study was conducted several years ago and was limited in scope, reducing the amount of salt pools and thus the occurrence of vehicle strikes was found to not only benefit the moose population, but also drivers in these areas as moose collisions often have higher rates of injury than collisions with deer and other small animals (Niemi et al., 2017).This is another factor that road managers should consider when planning their winter maintenance.

These are only a few examples of the species that are negatively affected by road salt use in North America. There are many more organisms likely harmed by the use of road salt in winter, which is a factor that should be considered when determining the types of interventions necessary for winter road maintenance.

Ecosystems

As evidenced by the negative effects that road salt can have on animals living near roads, it has the potential to affect the ecosystems that they depend upon. In fact, the Cary Institute, along with other research groups, have documented the increasing salinity of freshwater due to the winter application of road salt and other de-icers. The salinization of freshwater salinization puts water safety and quality for all organisms in the watershed- including terrestrial and aquatic organisms and even humans.

According to the Encyclopedia of Diversity (2001), freshwater ecosystems “consist of entire drainage basins as water moves from land and in groundwater runoff to stream and river channels, and to recipient lakes or reservoirs.” These areas provide habitat for nearly 10% of the species on Earth while covering less than 1% of the land, establishing their importance for biodiversity on the planet (World Wildlife Foundation, no date). An increasingly common phenomenon known as “freshwater salinization syndrome” has been identified in many freshwater ecosystems across the globe, with the link between freshwater salinization and road salt usage being identified as early as the 1960s in the United States (Kaushal *et al.* 2021). This salinization has potential for long lasting detrimental effects on the organisms living within these watersheds, with the salt that has already been applied expected to take decades to be fully flushed out. These elevated chloride levels caused by winter salting are not limited to the winter months, in fact the levels can be just as high in summer and are following the same increasing trend; this is concerning because chlorides are toxic to aquatic life in surface water (Kelly et al., 2008; Wenta & Wisconsin Department of Transportation, 2020). Studies have shown that the rise in salinity is not the only concern for the areas affected by road salt legacy effects, as Kaushal et al. (2021) illustrated that the salinization of freshwater has "direct and indirect effects on mobilization of diverse chemical cocktails of ions, metals, nutrients, organics, and radionuclides in freshwaters." The impact of these other stressors are additional toxic burdens to the organisms that are consuming the salinized water, which further damages the biodiversity these areas support.

The habitats that are directly most impacted by salting of roads are those that are immediately beside the road. Numerous studies have documented that areas closest to the road edge are subjected to high levels of salt accumulation due to bounce off or scatter of the de-icing salts (Kadoyu *et al.*, 2002). This can damage both the animals and plants living there, build up in the soil, and percolate into groundwater. The damage to roadside vegetation can occur across a broad range of species and exposure types. A study conducted by Trahan and Peterson at the University of Northern Colorado in 2007 found that the trees and soil closer to roadsides have higher levels of salts, and that foliar damage to roadside vegetation was correlated with the presence of salt ions in plant tissues. A critical finding of this paper is that elevated levels of sodium and chlorides present in the foliage of Colorado pine species remain throughout the year, suggesting that these tree species are exposed to stressful high salt conditions year round (Trahan & Peterson, 2007).This indicates that the vegetation present at the roadside are at increased risk of numerous negative repercussions throughout the year. These high stress environments can reduce their photosynthetic ability due to the degradation of photosynthetic tissues and have the potential to kill more sensitive species. Even with more resilient species, there is a possibility of reduction in growth. Overall, these high salt conditions can contribute to dieback caused by combinations of other factors including drought, cold damage, pollution, or rodent associated damage (Sucoff et al., 1975).

The increased concentration of salts in soil beside these roadside areas also reduces the suitability of soils to support vegetation; the specific salts present determine the types of damage that occurs, either to the soil itself or the roots and vegetation present. These ions can change the physical structure of the soil matrix, the osmotic potential of the soil itself (which can influence the availability of water to plants), and the nutrient availability of the soil. This is because the osmotic gradients of soil are crucial for water and nutrient retention and uptake, and the accumulation of salt ions can interrupt this gradient and reduce the suitability of soil to support plant life (Trahan & Peterson, 2007). This relationship between increasing salt ions and decreasing soil productivity has been identified and exploited for thousands of years; historical accounts from the destruction of the city of Carthage by the Romans accuse them of “sowing salt over the earth thereby making the ground infertile forever” and biblical accounts from the book of Judges tells a similar story of a king sowing his city’s soil with salt after revolts against him (Hilpold, 2020; U.S. Geological Survey, 2016). With this biological understanding and historical evidence of salt reducing the fertility of soil, it is seemingly counterintuitive to use the quantities of salt currently employed in the United States.

Anthropogenic Concerns:

Beyond the potential impacts of salt on natural communities such as freshwater, roadside ecosystems, and at-risk species, road salt has also been shown to have negative effects on the human population and infrastructure. Although drinking water in the United States is treated to prevent contamination of chemical and biological agents, the infrastructure used to make this water available is not necessarily free from contamination from build up of salts, lead, nitrates, etc. This means that although the water itself is treated, it has the potential to become unsafe for people to drink if the pipes and other infrastructure are not maintained properly. In fact, a study conducted by a hydrologist, Bruce Lindsey, with the US Geologic society found that conditions of high salinity and low pH in an aquifer in southern New Jersey “mobilized… radium—a radioactive element which is harmful to humans" (Hileman, 2023). This potential for drinking water to become unsafe is not exclusively of concern for individuals getting water from the city, but also for people that have private wells. The overuse of road salt has been found to contribute to the salinization of groundwater and private wells and has the potential to decrease potability of the water (Jamshidi, Goodarzi, & Razmara, 2020).

Human Health

A specific concern with the salinization of drinking water comes from the potentially life-threatening effects it can have on individuals that are on a sodium restricted diet. There is a threshold of 20 mg of Na/L that the EPA set based on sodium restricted diets and an additional 250 mg/L of chloride threshold under secondary regulations for drinking water in the United States (Hintz & Relyea, 2021). These regulations are intended to ensure that drinking water is safe for constituents, but studies from as early as the 1970s identified various private wells that had salt levels far exceeding natural levels and out of compliance with the levels previously set by the EPA. In fact, more recent studies have estimated that nearly 24% of private wells in New York state had been contaminated with road salt and a quarter of the participants had stopped using their well water out of concern for their health, and Wisconsin based studies have measured salt concentrations, finding some over 400 mg/L of chloride (Pieper et al. 2018, Rayne et al. 2019). The evidence of road salt intrusion causing concerningly high salt levels in water is abundant, and its potential effects for individuals on restricted salt diets is clear. If someone does not know the salinity of their drinking water, they could be unknowingly poisoning themselves, or at the very least unknowingly consuming levels higher than they realized or that is safe, regardless of dietary restrictions

Salt has been identified as critical for the maintenance of blood pressure and extracellular fluid volume in the human body, although health concerns arise as humans are not adapted to handle high levels of salt. The positive relationship between sodium intake and blood pressure have been investigated, with a correlation between high sodium diets and increased risk of cardiovascular diseases. In fact, reduced sodium diets are often recommended to individuals that have volume overload causing diseases including hypertension, liver cirrhosis, and diseases of the liver and cardiovascular system. When properly monitored, the salts themselves are unconcerning, but in the case of the unstructured addition of salt from road salts, they can (as discussed previously) also allow other harmful chemicals to be mobilized. These can include lead and arsenic, and these compounds have the potential to cause physical and mental impairments in children (Jamshidi, Goodarzi, & Razmara, 2020). The effect of lead on children has been understood for many years, and there is legislation intended to reduce the lead exposure in the United States although it unfortunately often falls short. The legislative oversight of lead mobilization abilities of water contaminated with high levels of road salt has been linked to the crisis in Flint, Michigan which will be discussed in greater depth when considering the infrastructure concerns for using road salt (Kaushal, 2016).

<u>Infrastructure</u>

The concerns for human health that the Flint, Michigan crisis highlighted are not limited to Flint. Many private well owners (nearly one quarter of private well owners in New York state) have had to treat their water or switch sources when their wells chloride levels were tested over EPA set limits for potable water. These effects are likely more pervasive than we realize, as water quality issues often are overlooked until the water exhibits noticeable signs, such as tasting bad. Pipe corrosion is of large concern, as the pH of water lowers with increased levels of salts and can lead to the pipes being 'eaten away' and releasing the metals and other built up materials from the pipe walls. Unfortunately, the EPA estimates that there are nearly "9.2 million lead service lines (LSLs)" that provide water across the United States (*Lead Service Lines,* 2024). This suggests that many people across the country are at risk of lead contamination in their drinking water, which can cause various detrimental effects on humans at all stages of life.

Infrastructure

- Effect on pipes- Flint crisis (Hileman, 2023)
- Private wells (Pieper et al., 2018)
- Infrastructure (Picinich, 2021; Schwartzberg, 2016; Vitaliano, 1992; *Limit Bridge Deck Corrosion,* 2017)

Alternatives

Current aka "Partial Solutions"

- Brine- liquid salt, organics
- Alternative de-icers- magnesium, calcium, etc
- Better computer controls on trucks
- Snow tires or snow chains
- Reduce service on more roads- China, US
- Best management practices- being there at the right time with the right amount of salt

Reference conversation- email communication from

Interesting Potential Solutions

An interesting novel technology for road salt alternatives being tested in the United States is the use of heated pavement, which has been tested at Rowan University (Rowan Today, 2023).

- Coated wood chip (Maloney, 2022).
- Heated pavement (Rowan Today, 2023)

Call to Action

Although the use of road salt for the purposes of road safety is likely not going to be completely abandoned any time soon, there are things that individuals can do to reduce the negative effects of excess road salt release into the environment.

The first is by reducing the amount of salt you use personally. Public awareness about the proper use of salt is limited, although guidelines are readily available both online and often on the packaging of the de-icers. In order to adequately cover 20 feet of driveway, only 12 ounces (equivalent to a small coffee cup's worth) of road salt are needed to maintain a safe surface for cars and people. Additionally, the effectiveness of ice depends on temperature, so a warm snowy day would require a lighter application of road salt than a winter day with temperatures below 20 degrees Fahrenheit. Shoveling before applying de-icers is also a relatively easy way to reduce the amount of road salt people use personally, as snow covered driveways need more salt to ensure percolation of the de-icers to the pavement surface for them to work effectively. Shoveling before salting reduces the excess salt needed to ensure the safety of sidewalks, driveways, and roads.

An additional thing that individuals can do to reduce their release of excess salts in winter could be recovering unused salt. It is quite common practice for salting to occur in preparation for a big storm, and it is also not uncommon for the storm intensity to be lower than predicted or for the storm to redirect or dissipate before hitting an area. In cases like these, where salt has already been applied but is not necessary for the current conditions, collecting the salt that remains on driveways, sidewalks, and roadways may be another avenue for reduction in road salt intrusion. It could be as simple as taking a broom to the sidewalk or driveway and gathering all of the salt to put back in its storage container, although this likely would come with more challenges on a larger scale.

Individuals should also call upon their local government (sustainability committees, city council, DPW, conservation commissions) to educate the public about the dangers of excess road salt use, and inform them on the ways they can personally reduce their contribution to this problem. One concern that could be addressed with this involvement of local authorities is the liability issue that may arise when people and businesses consider reducing their level of salting. Laws about liability regarding slip and fall accidents due to salting are likely difficult to decipher for many, and therefore oversalting is common to reduce the risk of liability. If states or cities published guidelines for road salt application, then businesses and homeowners would know the amount of salt they need to use to keep walkways and roads safe and reduce their liability of “slip and fall” lawsuits. Following these mandates would reduce the individual risk of litigation and also reduce the amount of excess salts used to “cover their bases” and prevent injury. These guidelines could potentially include a clause suggesting or mandating the pickup of excess salts spilled or otherwise released during application that is not necessary to maintain the safety of surfaces in winter conditions.

Finally, suggesting and encouraging your state to make use of federal funding to improve their infrastructure and reduce the risk of human health effects is another way that individuals can get involved. The EPA offers state revolving funds to assist states with maintaining their compliance with the Safe Drinking Water Act, and this program is known as The Drinking Water State Revolving Fund (DWSRF) and it "provides below-market rate loans to fund infrastructure improvements to water systems to protect public health… These projects may include the installation, upgrade, and replacement of treatment facilities, finished water storage facilities, and transmission and distribution systems" (*EPA State revolving funds*, 2023). When interviewing an individual from the EPA Division 1 Water Quality Division, they mentioned that these funds may be possible to use for creating wetland type environments near roadways. These types of additions would likely contain halophytic plants that could potentially capture the excess road salt in these areas, such as the native species *Typha latifolia* or the invasive *Phragmites* species. Previous research has shown that these wetland species are capable of retaining both salt and chlorides in their tissues, sequestering it from percolating into groundwater and causing widespread negative effects (Monks et al., 2023) and Morteau et al., 2009).

Additionally, the EPA works with entities in cities (such as in Hartford, Connecticut) to assist them with understanding the process needed to join programs and get federal funding for transitions to green infrastructure, which is a term that describes using natural solutions to ameliorate or solve anthropogenic climactic problems. The city of Hartford intends to build various forms of green infrastructure to mitigate the environmental issues that the city has identified as problematic. Some of these measures include creating artificial wetlands near roads to reduce the runoff of pollutants into the environment (as discussed previously), building accent geography to direct water flow and speed, and using previously identified brownfield sites to created retention areas to safely store overflow of wastewater treatment plants to reduce the occurrence of untreated water release due to overburdening of wastewater treatment plants.Brownfield sites are (according to the EPA) an area of land that may have complications with development, reuse, etc. due to the potential presence of pollutants, contaminants, or other hazardous substances (Brownfields, US EPA*)*.

All of these road salt alternatives and mitigation techniques for individuals and entities can help reduce the release of road salt into the environment, and any amount of reduction should be considered a “win”. This is a big problem without a ‘silver bullet’ solution, but we aren't helpless- we can utilize and even go beyond the current alternatives to create novel technology and techniques to keep roads safe in winter without risking the health of humans, animals, and the environment.

Credits:

Thank you so much to Professor Rick Reibstein for always encouraging me to look beyond the current partial solutions available for road salt use, and never forgetting to remind me that unused salt can be picked back up. Additionally, thank you to my fellow classmates in EE538 for their suggestions, and the experts I talked with that were more than happy to help me understand this problem.