Road Salt Effects on Freshwater Ecosystems in the Northeastern United States

By

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April 2022

Submitted in fulfillment of the senior thesis requirements of the
Department of Environmental Science at Allegheny College
and approved by the senior thesis committee.

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Acknowledgements

I would like to first thank my family, specifically my siblings, who have pushed me to be the best version of myself, and provided me with the best role models I could ever ask for and continue to push me to strive for greatness in all that I do. Similarly, I want to thank my parents for all of their support in all of my academic endeavors thus far and all that they will continue to do for me in my future education and career efforts. I truly appreciate their support in all that I do, whether it be in the classroom, on the field, on the stage, or anywhere life takes me, they are always my number one supporters and loudest cheerleaders. I would not be where I am without their help and their encouragement throughout these past twenty two years and I am eternally grateful for that. Also thank you Addie and Lucy, you are the best dogs ever, and seeing a picture of either of you always brightens my day!

I very much would like to thank my senior project advisor, Professor Kelly Pearce, for all of the help that she provided me, whether just encouraging me to work on my project or giving me specific aspects to work on and alter to get my best work as a result. Thank you also to Professor Rich Bowden, my second reader, for encouraging me to "think outside the box" and narrow down what it actually was that I wanted to research. Without both of your help, I would not have been able to finish this project and create what it is today. I would also like to thank lab technician Sam Reese for always allowing me to squeeze in some time to use the AAS machine whenever I was free between classes and lacrosse practices. Thank you!!

I also would like to thank my incredible boyfriend, Jake, who has been there for me the past five years, not only as my incredible support system, ear to listen, and also as my very best friend. I couldn't imagine life without you, and the support that you have given me through my entire education at Allegheny has been so appreciated. I truly am so grateful for your incredible support, especially all the three hour drives you have taken to see me. You give me so much to look forward to, and give me so much to be grateful for in my life. I would also like to thank my amazing lacrosse teammates, for being there for me whether it's just having a good time, winning or losing games together, pushing each other to be the very best at practices, you all have been such an influential aspect of my life and have been such a rock in my life during this entire process. I also want to thank my previous lacrosse coaches, Coach Hughes and Coach B, in their dedication that they always had in our program and the confidence they instilled in me. The trust they had in me helped me to become the best version of myself as a lacrosse player and as a person overall. Thank you to all my friends, who although very stressed about their own senior projects, were there for me and always asking questions about what it was that I was doing, and having lots of interest in what I had to say.

Abstract

This study investigates the effects of road salt applied to roads near a body of water on freshwater ecosystems, specifically in the headwater streams that feed into French Creek in Crawford County, Pennsylvania. The sodium levels were observed through water sample collections from ten total different points throughout two different bodies of water, Gravel Run and Cussewago Creek in October 2021, January 2022, and February 2022. Gravel Run feeds into French Creek from the east, and Cussewago Creek feeds into French Creek from the west. The collection sites were recorded from upstream to downstream, anticipating that the samples collected more downstream would have lower sodium levels due to the potential for dilution as the water is carried further downstream. The resulting control sodium levels proved to be relatively low, averaging about 3.6 ppm. The sodium levels that were collected after salt was heavily applied to the roads indicated that at almost all of the collection sites, there was an increase in the sodium level, indicating a higher salt presence. The samples taken during winter time averaged a sodium level of 4.9 ppm. The final round of samples, collected after heavy rainfall, indicated an average of 5.3 ppm of sodium. There was a general upward trend in the levels of sodium levels across the three collection months, indicating that the presence of road salt on roads parallels an increase in the sodium levels in the nearby waterways. The resulting sodium levels at various points down the creeks indicated that sites close to roads (relative to sites further away or downstream from these sites) indicated higher levels of sodium, or a higher presence of road salt or potential for road salt to affect the water chemistry in these locations. The implications of the high presence of road salt and similar sodium content has the ability to alter ecosystems and create an environment not suitable for native organisms.

Introduction

Driving in the winter time in a region with substantial annual snowfall can be difficult and hard to handle. This is a human safety concern in regard to car accidents, so departments of transportation utilize road salt–traditionally a mix of naturally-mined halite–which has been demonstrated to reduce accidents by up to 93% (Lab Notes, 2018). As salt divides into its sodium and chloride ions during dissolution (mixing with water) it can be absorbed into roadside plants, licked/eaten by wildlife, or accumulate in aquatic ecosystems, which can have large impacts on the health of the surrounding environments (Learn, 2018). There are two types of icing throughout the winter; anti-icing is laying salt before the snow falls in a preventative sense, and deicing, which is the addition of road salt after a snowstorm has already taken place, which may take longer to decrease slipping because the salt needs to permeate through an already established layer of snow. Half of applied road salt is thought to enter surface waters near the site of application via roadside drainage networks (ditches, culverts, or other networks intended to convey stormwater away from the road surface and into a nearby waterbody), and the other half is either removed during snow removal or enters soil and groundwater (Daley et al., 2009). This stormwater or snowmelt has the potential to enter groundwater or drinking water, and have detrimental human health impacts, such as increased sodium intake through direct consumption of diluted road salt via drinking water.

Road salt usage in the United States has increased steadily beginning in the 1940s through the current decade, effecting increased concentrations of salt in waterways, especially in closer proximity to roads (Corsi et al., 2010, Blasius & Merritt, 2008). In the Adirondack Park located in upstate New York, chloride concentrations downstream from a major road were sometimes 31 times higher than concentrations when compared to upstream levels, though each measurement depends on the proximity of the portion of the stream being tested in relation to the road (Blasius & Merritt, 2008). Further, a study in southeastern New York showed that salt for deicing accounted for 91% of the sodium chloride input to the watershed in that area (Kelly et al., 2008). In the state of Pennsylvania, to prevent ice from building up on the road surface, Pennsylvania Department of Transportation (PennDOT) trucks spread a mixture of salt to melt the ice and small anti-skid stones to provide traction for vehicles. In some rural areas of the state, salt use is limited, and anti-skid is increased because salt depends on a certain amount of traffic in order to be fully effective (PennDOT, 2021). In the winter season of 2020, PennDOT used more than 8.3 million gallons of salt brine for anti-icing roadways before a storm event (PennDOT, 2021). In some cases, when predicted storms don't come to fruition, there is the potential for excess amounts of salt to be utilized. For example, during the 1980 Lake Placid Olympics, the state heavily salted the surrounding roads in anticipation of heavy traffic. Due to a lack of snow, this salt ended up being washed away,

causing additional unnecessary sodium and chloride levels into the surrounding environment (Rivard, 2021).

Salt can alter the properties and chemical makeup of the freshwater that it enters; for example, salt ions attract water molecules, leaving fewer hydrogen and oxygen ions available to capture and disassociate gas molecules (Kielmas, 2018). In many locations, water-soluble iron cyanide compounds are widely used as anticaking agents (prevents clumping) in road salt, which are chemicals that are not normally present in freshwater (Paschka et al., 1999). Water exposed to abundant halite dissolution, or the division of the salt into ions within a solution, may present a different type of pollution that is not specifically covered by environmental policies and regulations, so there may be chemicals present that are not typically tested under drinking water regulations (Daily et al., 2014). A study examining the drainage wells of one city, which are likely to be dominated by halite (applicated road salt) during the cold seasons, revealed generally higher amounts of chloride (more than 5 times on average) relative to those in a similar city studied that tends to use reduced levels of road salt in the winter months (Jamshidi et al., 2020).

Road salt introduces various chemicals and increased ion concentrations to the water and can alter the biological processes of organisms. At the early stages of development, road salt can have dramatic effects on embryonic development of some amphibians (Hintz & Relyea, 2018). These chemical shifts can ultimately alter food webs, being detrimental to many species (Findlay & Kelly, 2011). Higher levels of salt can kill tiny, shrimp-like amphipods which provide important food sources for fish and insects as well as snails and clams. It can also kill off zooplankton, the abundant organisms that form the baseline resource for entire ecosystems—which can inversely cause the population of phytoplankton they feed on to go up, and ultimately create a loss in biodiversity and increased algal blooms (Vonderembse, 2019). Rising salt levels can make some environments more vulnerable to exploitation by salt-loving invasive species (Learn, 2018). As road salt increases the salinity of water bodies, the additional salt can help invasive and non-native species to prosper, while also creating increased danger due to deer (*Odocoileus virginianus)*, moose (*Alces alces)*, and other large mammals drawn to salt-covered roads in search of a salty snack.

Especially in regions that experience relatively colder winters, the application of road salt has caused the salinity of many freshwater ecosystems to rise sharply over the past few decades (Coldsnow et al., 2017). In the northeastern United States, chloride concentrations in surface water are increasing from road salt at a rate which could threaten fresh water availability for humans and the habitat of aquatic communities in the near future (Jin et al., 2011). Observed increases in sodium and chloride concentrations in the Mohawk River in New York from the 1950s to the 1970s have also been seen at harmful rates (Godwin et al., 2002). The seasonal cycles of water chloride concentrations (high in winter and early spring, lower in fall) point to road salt applications as the cause of increased lake salinity in the

urban bodies of freshwater (Novotny et al., 2008). Application rates of road salt in the United States tripled from 1975 to 2005, reaching nearly 25 million tons per year (Moore et al., 2013). If salinity were to continue to increase at its present rate due to changes in impervious surface coverage and current management practices, many surface waters in the northeastern United States are predicted to not be potable for human consumption within the next century due to lack of enough time to reset to natural levels of these elements (Na and Cl) (Kaushal et al., 2005).

Recently, however, there has been legislation aimed at reducing the amount of road salt pollution, or the utilization of alternative anti-icing and de-icing products. For example, in July of 2020, former New York State Governor Andrew Cuomo signed the Randy Preston Road Salt Reduction Act, intended to reduce the amount of road salt pollution in the Adirondack region. This remains a trial run for utilizing alternatives, as this process is one that will take some time. A "Road Salt Reduction Task Force" has been created to research effective alternatives which will be trialed over a three year salt reduction program in an attempt to prevent pipes from eroding, ecosystems from being negatively altered, and groundwater contamination (Cerbone, 2020).

Characterizing and noting the pathways where salt is carried to water bodies is critical to being able to predictively model road salt runoff and assess future impacts (Moore et al., 2013). Too high of a concentration of salt in freshwater ecosystems has been shown to reduce the amount of female amphibians, and can also contribute to an amphibian's reduced osmoregulation capacity, or the process to regulate water content in an organism (Hintz & Relyea, 2018). In one study by Learn (2018), frogs were raised in different tanks from eggs and dissected to determine that the number of male tadpoles that survived hatching increased by 10 percent, from 40 percent to 50 percent. Fewer females could mean fewer eggs laid, causing drastic population level changes over time. In a study conducted near Pittsburgh, PA, the shock loads of salt experienced were sufficiently elevated, causing concern about the osmoregulatory stress to freshwater organisms (Koryak et al., 2001). It has been concluded that chloride concentrations in waters due to application of de-icing salts influenced the freshwater community structure by excluding salt intolerant species (Collins & Russell, 2009).

The Meadville, Pennsylvania area averages about 75 inches of snow a year, thus making northwest Pennsylvania a region that gets heavily salted in the winter time to prevent car accidents and improve the grip of tires from this high amount of lake effect snow. The conservation of French Creek and the creeks that feed into it are so vital in preserving the high levels of aquatic biodiversity in this area of the country. There is a high density of mussels in French Creek, playing a large role in the biodiversity of the creek. Mussels contribute to the purification of aquatic ecosystems in making food sources more visible for other organisms through the consumption of plankton and other microscopic creatures, and an increase in levels of unnatural elements can interfere with this water filtration. A study conducted by

Smith and Crabtree (2010), concluded that there are approximately 22 million freshwater mussels in a 2.04 m^2 study location in the main stem of French Creek, indicating that their survival is critical to the ecological health of the region.

The location of study in this research were two different creeks that feed into French Creek. These creeks are Gravel Run, located east of the main stem of French Creek, and Cussewago Creek, feeding into French Creek from the west. The objective of this study was to observe the sodium levels at various locations of these two creeks prior to and following the application of road salt to the nearby roads. The goal was to explore whether the sodium levels increased following road salt application, as sodium is a key ingredient in road salt and is a good indicator of salt presence because it is a direct result of the dissolution of road salt. The levels of sodium were tested before any snowfall in the fall, and during the wintertime after a period of heavy salting and snowfall, to examine alterations in sodium levels due to the increased application of road salt during those time periods. This study also investigates road salt alternatives that are to be assessed for feasibility, and analyzes the potential negative effect that the measured and collected levels of sodium can have on freshwater ecosystems like the ones in these creeks.

Methods

On 28 October 2021, 20 January 2022, and 27 February 2022, I collected one 250mL vial of water from five different locations along two different streams that feed into French Creek in Meadville, PA (Figures 2, 3, 4). These two streams were Cussewago Creek and Gravel Run in Meadville. These two creeks are classified as an order of 1, indicating they are a headwater stream, whereas French Creek is classified as an order of >5, indicating it has many confluences and creeks that feed into it. Additionally, there exists large amounts of data on French Creek because of its recognized biodiversity, so I was hoping to collect new data in this area, with creeks that are slightly further from heavily used roadways. The initial values collected in October 2021 are considered the control values of the sites in regards to sodium content, as these water samples were recorded prior to any snowfall and any salt application to roads for over 6 months. It was hypothesized that the sodium levels were to increase in the following collection periods because of the application of road salt to nearby roads, adding sodium and chloride ions to the water's chemical makeup. Within each creek, five points (latitude and longitude) were recorded as the locations of water sample collection (Table 1). These five locations were distanced at least 100 yards further downstream from the previous collection location. The vials were initially washed with a 10% HCl and diluted water mixture prior to collection and mixed around for about 5 seconds, then rinsed through once more at the collection site with the creek water. Once collected, the water samples were labeled (site 1, site 2, site 3, etc., respectively) and then stored in a refrigerator located in Carr Hall at Allegheny College, kept at 40°F (4°C).

This process was utilized because I knew it would provide an accurate reading as to where there are higher levels of sodium, most likely from road salt application in the studied creeks. The collection method was based on a similar case study examining the retention of sodium chloride in a watershed in southeastern New York (Kelly et al., 2008). The five different locations in each creek were utilized to see the distance of which detectable sodium levels are shown throughout a certain length of a specific creek. To hypothesize if the sodium levels were to lower in areas that are further down the sampled creeks compared to more upstream, these water samples were collected alongside a thorough literature analysis to discover the effects that road salt can have on freshwater.

After being collected, the sample vials were labeled with their location (creek name, and number of site location), time and date of collection, and then analyzed for their levels of sodium. Following collection, the water samples were put through an Atomic Absorption Spectrometer (AAS) machine. Prior to the six water samples being run in the AAS machine each time, a calibration was performed with controlled sodium levels to guarantee the accuracy of the detections to create a baseline in the medium being tested. This machine utilizes a flame and a specific lamp(s) for the detected element (sodium in this case) and detects elements in either liquid or solid samples through the application of characteristic wavelengths of electromagnetic radiation from a light source (flame). The atoms in the flame are moved to the excited state from the ground state and when they return to the ground state, the emission of light occurs from the detection of the element you are measuring for (Beaty & Kerber, 1993). In the instance that the sodium levels in the water sample were too high to be detected by the machine, the samples were diluted using distilled water to detect the parts per million (ppm) of sodium in the water sample. All of the samples in this research were diluted by a factor of 20, so a ratio of 20:1 was utilized of distilled water to sample water. This final concentration number is recorded in ppm after multiplying the diluted value by 20 to compensate for the dilution (Figure 1). Each level of sodium was recorded and noted each time the samples were run through the machine. When running the final round of samples through the machine from the February collection date, there was a malfunction with the AAS machine, and after the machine was calibrated and five samples were run, the computer indicated that the machine was having a difficult time maintaining a steady level when in the control water, so a new calibration was performed–a two point calibration as opposed to a four point calibration–to create an accurate base reading for the variable concentrations.

Results

The resulting sodium levels in the water samples were collected to observe any discrepancies in the collections, to provide data that shows if there are measurable differences in the sodium levels at varying points in these creeks, and if there was an observed difference in water chemistry at different points of the year. The final sodium levels that were detected indicated variations in the sodium levels over time; however a general increase in sodium levels was seen, indicating the predicted alterations to water chemistry in regard to sodium ions from the onset of the winter seasons and the increased application of road salt (Figure 1).

The average sodium levels collected on each of the three dates (October 28 2021, January 20 2022, and February 27 2022) were recorded and compared to one another to indicate the runoff of road salt into the waterways that were being collected during that specific time of the year. The sodium levels that were collected in October were relatively low at all of the sites, averaging around 3.7 ppm of sodium. In January, following periods of heavy snowfall and heavy application of road salt onto the roadways that surround both of these waterways and French Creek, the sodium levels that were collected averaged 4.9 ppm. This indicates an overall increase in the average level of sodium that was detected across all of the ten collection sites. In February, following periods of heavy snowfall followed by heavy rainfall, thus exacerbating the process of runoff and specifically the runoff of road salt from the roadways and down hills to eventually reach nearby waterways, the average sodium level that was detected was 5.3 ppm of sodium (Figure 2).

Additionally, an analysis of variance statistical analyses were run for both Cussewago Creek and Gravel Run. The resulting data showed that there is no statistically significant difference in the sodium levels that were collected more upstream versus more downstream in both creeks (Cussewago Creek; $p=0.543$, Gravel Run; $p=0.763$).

Table 1: Summary of Site Data

Location	Site #	Latitude	Longitude
Cussewago Creek	1	41.649896ºN	80.183657ºW
Cussewago Creek	2	41.649666ºN	80.182939ºW
Cussewago Creek	3	41.649288ºN	80.182660ºW
Cussewago Creek	4	41.647170ºN	80.171079ºW
Cussewago Creek	5	41.646660ºN	80.169345ºW
Gravel Run	6	41.752342ºN	80.087979ºW
Gravel Run	7	41.752823ºN	80.088814ºW
Gravel Run	8	41.753954ºN	80.103305ºW
Gravel Run	9	41.759608ºN	80.103970ºW
Gravel Run	10	41.758358ºN	80.109341ºW

Table 1. The number and location of each site in Meadville PA and Saegertown PA, as well as the latitude and longitude of each location that the water sample was taken from on 28 October 2021, 20 January 2022, and 27 February 2022.

Figure 1: Comparison of Sodium Levels at all Ten Sites

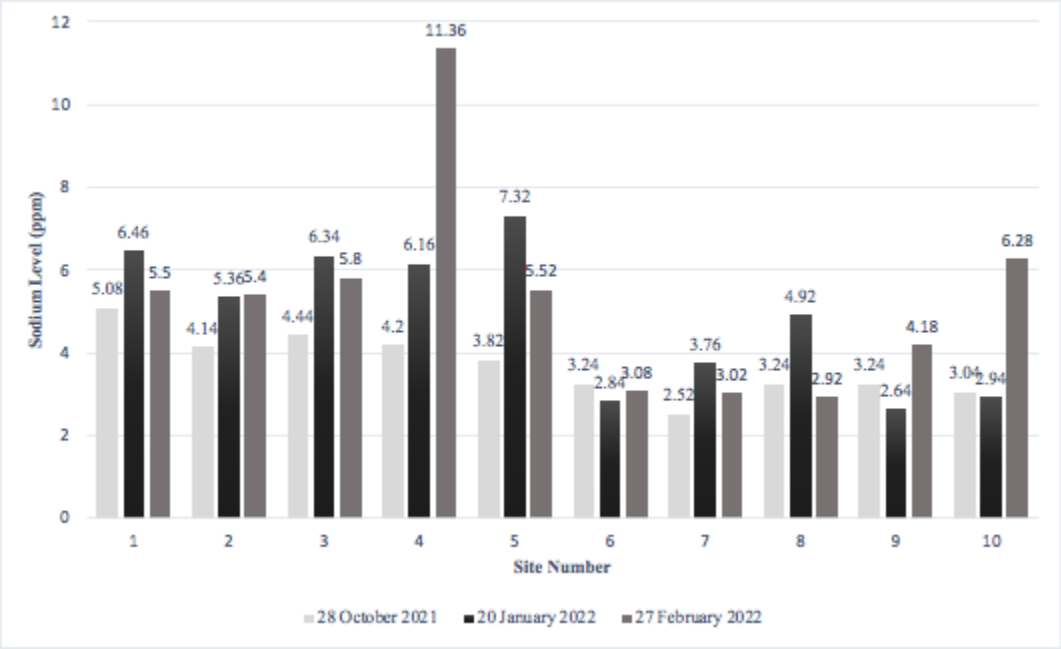


Figure 1. The detected sodium levels are shown at each sample site in Cussewago Creek and Gravel Run on 28 October 2021 and 20 January 2022, and 27 February 2022. The lightest shaded bar representing the October collection date, the darkest shaded bar representing the January collection date, and the gray shaded bar representing the February collection date. The sodium level is represented as a number as parts per million (ppm), indicating the milligrams of sodium per liter of water. The sites numbered 1-5 are collected from Cussewago Creek in Meadville, PA, and the sites numbered 6-10 are collected from Gravel Run in Saegertown, PA.

Figure 2: Average Sodium Levels From Each Collection Period

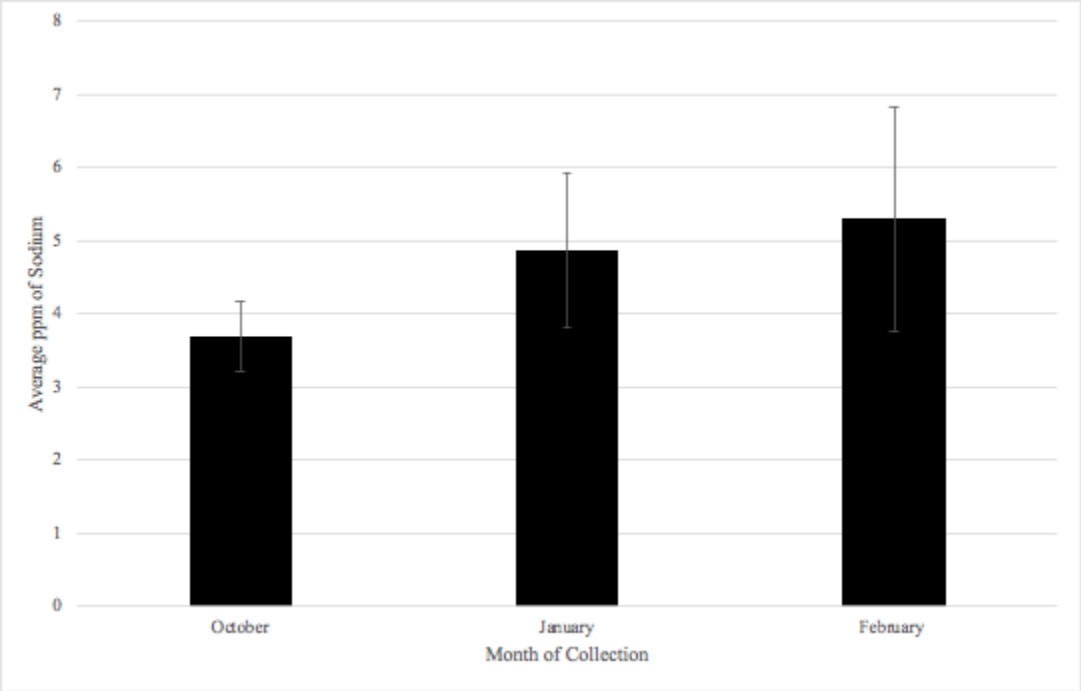


Figure 2. The dates of collection (28 October 2021, 20 January 2022, and 27 February 2022) are shown along with the average sodium content (ppm) of all ten sites that were collected from Cussewago Creek and Gravel Run in Crawford County, PA on that prospective day in order to see the overall trend in sodium content in the waterways that were collected from. Error bars represent a 95% confidence interval.

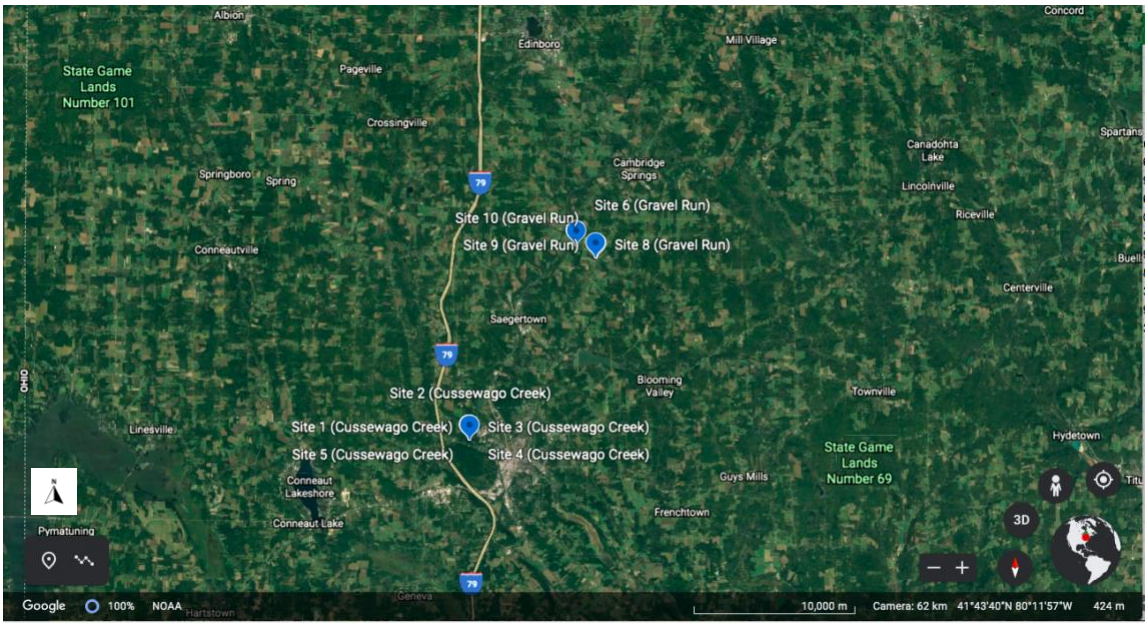


Figure 3. A map is shown of all ten of the sites throughout Crawford County, PA (sites 1-10) that were collected in October 2021, January 2022, and February 2022 to measure the sodium levels in these ten different collection areas.

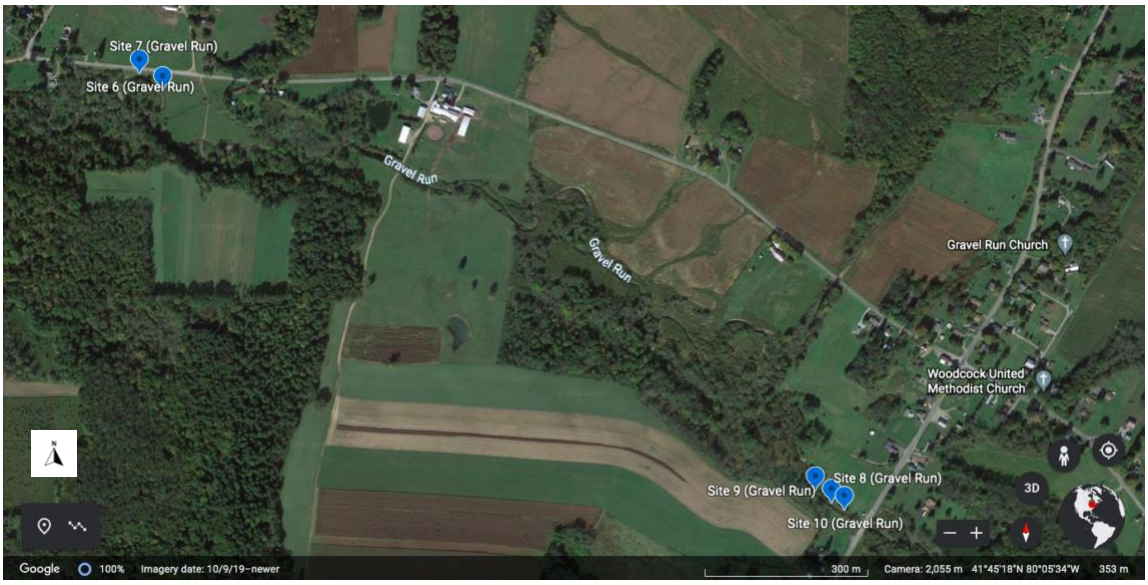


Figure 4. These are the five sites from Gravel Run, located in Crawford County, PA (sites 6-10) that were collected in October 2021, January 2022, and February 2022 in order to measure the sodium levels in these five different locations



Figure 5. The five sites that are located in Cussewago Creek, Crawford County, PA (sites 1-5), water was collected in October 2021, January 2022, and February 2022 in order to measure the levels of sodium in those five locations of the creek; each site being about 100 yards further downstream than the previous, scaling about 400 yards in total across sites 1-5.

Discussion

The findings from this project indicate an increase in the sodium levels in freshwater creeks during the wintertime, or during periods of high road salting activity, compared to periods of low road salt application, or prior to any snowfall in the region of Crawford County, PA. The hypothesis that there would be decreased levels of sodium further downstream, indicating lower prevalence of road salt in the portions of the creek that are further from the head stem, was shown to be true only in one of the creeks, Gravel Run (Figure 2). Both creeks, however, did show a general increase in the sodium levels at most sites following snowfall and road salt application in the winter time. A final average of about 5.6 ppm of sodium at the end of the winter time is relatively low in comparison to ocean water and the safe levels for drinking water, so such a miniscule increase could potentially have little effect on aquatic organisms and their functions. However, the final collection of water samples in the late winter indicated a somewhat similar content of sodium as compared to the prior collection date, except for a couple of sites that indicated a high jump in their recorded sodium content. These sites were sites four and ten, and site ten being about 40 meters from the closest roadway. Site four is over 400 meters away from the nearest

roadway, so this large jump could be due to other unidentifiable factors. This indicates the importance of a riparian buffer zone, or an area of land directly bordering a waterway with lots of vegetation on it to hold the banks of the waterway in place and prevent erosion from altering the characteristics of the stream/creek. These areas are also essential in the absorption of material and nutrients into the soil prior to runoff entering the waterway, in hopes of preventing unwanted material, such as road salt, into the water.

There could be locations along the creeks that are closer to roadways thus making it easier for salt to run off into the waterways. There may be a higher addition of road salt further upstream in the creek at other sites, as when the water travels further down the creek, there is increased movement and increased oxygen levels, "cleaning" and oxygenating the water as it moves, thus the sodium levels are filtered out and diluted in the water. With this in mind, this could indicate that smaller creeks may end up with higher sodium levels or indicators of road salt use than larger streams because of larger streams having the capability to easily filter out the unnatural material in the water. This could mean that ecosystems that are more complex and in larger streams are more protected from road salt because of their vast nature and ability to have complex systems to help fight off the non naturally-occurring material. In Cussewago Creek, the sodium levels after snowfall in the locations more downstream didn't show a decrease in the sodium levels compared to more upstream (Figure 2). Factors such as distance from the roads or portions of iced over water could cause the data to differ from the hypothesized results. Utilizing French Creek observations and citizen science to collect a large amount of data on the chloride concentrations in French Creek, recorded increases in the chloride concentrations of the water collections has been shown throughout the onset of winter in 2022, correlating to the data collected in this research (Creek Connections, 2022). This could ultimately affect the very complex biodiversity of French Creek, a creek that has been accredited for its uniqueness and high biodiversity levels. With increases in ions such as sodium and chloride from road salt application and runoff, there is potential to create an environment that is not suitable for native organisms that are important in maintaining this biodiversity.

Other researchers have looked into alternatives to road salt that have the potential to melt ice on roads to reduce the risk to those driving on them, or to simply increase the grip of the tires on the road to reduce slip. Many alternatives to road salt have been researched and tested to see the effectiveness of more environmentally-friendly options in order to reduce the detrimental effects that road salt has on the freshwater aquatic ecosystems that are so important to the biodiversity of regions across the globe. A study investigated the effect of more eco-friendly salting options on freshwater mussels, a very important indicator species that is also essential for filtering water in freshwater ecosystems (Gillis et al., 2021). Freshwater mussels were exposed to diluted solutions of three different products, and beet juice was observed to be toxic to young developing mussels in their early growth stages at lower levels than the other products that were tested. Freshwater mussels are bivalves that live in lakes, rivers, and streams all

over the world, and they play vital roles in the environment and economics of many regions, indicating their high importance to many societies (Strayer, 2008). French Creek has 29 different species of native mussels, and two of these species are classified as endangered, so the conservation of these species are especially important in the observed waterways. They are important in the preservation of complex and healthy ecosystems, so indicating the effects that road salt may have on these organisms is essential in understanding the effects that road salt can not only have on individual organisms or species in freshwater, but also entire ecosystems.

Similar to freshwater mussels, many native fish in the northeastern United States can help to indicate a healthy ecosystem with their presence in the waterway. An investigation of the alteration of the spring mix of water layers indicates high levels of chloride on the bottom layer of Mirror Lake, in New York in the winter months, in parallel with the utilization of road salt this part of the year, due to a lack of mixing of the layers (Wiltse, 2022). Spring mixing, or when the layers of the lake or body of water get mixed for the sustaining of a healthy ecosystem to satisfy the needs of the organisms living at each layer, is essential in the life cycle of many aquatic organisms. This lack of water layers mixing and alterations in the densities of the layers increases the anoxic conditions (oxygen absence) of these layers, reducing habitat for local trout populations. This prolongs the recovery period during the spring and summer time for the body of water to adjust and return to normal after periods of reduced salt levels. This has the potential to occur in French Creek and its connecting waterways, which can alter the environment that the fish populations live in and affect their survival and growth rates in a negative way due to imbalances in the chemical makeup of the layers of the water.

Another similar investigation was carried out to observe the counteractive effects that differing organic additives to road salt may have on the freshwater environments that are receiving the washed-away road salt via precipitation (Schuler et al., 2007). The introduction of the organic additives to road salt showed an initial reduction in the amount of dissolved oxygen in the water, and microbial activity indicated that the unusable phosphorus was then altered into a usable form for the algae in the water, thus exacerbating algal growth leading to zooplankton abundance in this particular waterway. The findings indicate that multiple trophic levels have the capability of being altered from the introduction of road salt and other alternatives such as organic additives, even at very low concentrations (Schuler et al., 2007). There is still more research to be done in various settings and with different road salt alternatives in order to see the most economically feasible and environmentally friendly options for applying materials to roads to reduce the harmful effects that ice poses to human lives on roadways in the wintertime. An experiment could be run in order to see the level of salt that ultimately affects mussels and their productivity in a freshwater ecosystem. A study like this has not been done in this region, and it would be

interesting to see the level of sodium and chloride that ultimately have a measurable impact on these essential organisms.

In addition to the dissociation of sodium and chloride from the dissolution of salt in water, there are other factors that may be considered when looking into the environmental effects of the application of de-icing agents to roads. These include anti-caking agents; typically in the form of water-soluble iron-cyanide. These anti-caking agents pose an additional threat to the aquatic ecosystems and groundwater to which they are introduced via precipitation and runoff. Although these anti-caking materials are greatly beneficial in inhibiting clumping of road salt on roads, as they break down, they pose a threat to water quality in their rapid decomposition when exposed to light, leading to extremely toxic free standing cyanide in aquatic systems (Jain, 2018). This possibility to pose a threat to local waterways is more problematic in waterways close to large exposed salt storage piles, which does not apply to French Creek (Jain, 2018). The water quality effects of iron cyanide have not been thoroughly examined, so this is a topic that would benefit greatly from the additional research.

Limitations to this research include the fact that field work is being done in the winter time to monitor the water chemistry, so there is the potential for the body of water to be frozen, or for conditions to be unsafe for sampling. To obtain more accurate and more interesting results with higher levels of the measured sodium, I should have done the collections in the early fall, late fall, and then again in the springtime when the snow has begun to melt and the creeks are unfrozen. This would help to break down the snow barriers that are created from snow plows alongside the roads, and therefore the salt is more likely to easily run down into the nearby body of water that receives the precipitation runoff. Also, I think that more specific details on what the current weather is described as and the most recent precipitation date and type would aid in the detail and accuracy of the results. There would need to be more data like these compiled to draw accurate and meaningful conclusions for the French Creek watershed. Although there is a lot of research that states that there is an increase in the levels of these ions and overall salt levels following the application of road salt, the data that was collected was to be utilized specifically for French Creek data to add to any prior research done in the externalities of road salt on aquatic ecosystems.

Further research could include the utilization of more water collection sites for more accurate data to see more patterns between the presence of road salt on the roads and the presence of sodium in the creeks. Salt is a very dense substance, in that it has the capability to sink lower in a body of water, therefore the techniques utilized in this research may not have obtained an accurate reading of the actual sodium level, in that there is most likely a higher sodium content in the streambed, or the bottom-most layer of the creek. Collecting more than just one sample each time samples were collected would also create more data and therefore a more accurate data set for drawing conclusions based on the research.

Similarly, laboratory technology also has the potential to malfunction. In one of the runs that was done for this research, the Atomic Absorption Spectrometer was malfunctioning and not recording properly, indicating that there may have been implications with the sodium lamp that was being used. This is always a possibility, so knowing how to re-calibrate or perhaps use another method of measurement is always a good idea. In addition to water collection, laboratory tests could be run on more specific organisms, such as native fish and plants to see salinity level effects on organisms over time and at different stages of their life cycle. Research and lab work could be done to test alternative solutions to road salt on organisms at various points in their life cycle. Human opinions could be taken into account through a survey to see the relative perception of safety in regard to various alternatives to road salt on the road while driving. Implementation of road salt "task forces" and conversations have begun to be utilized in areas that are concerned about the extremely high amount of road salt being used in certain areas. These "task forces" have been shown to be effective in brainstorming potential road salt alternatives or methods that can be used to reduce the total amount of applied road salt (Cerbone, 2020). In the state of New York, a summit was held in 2021 in order to address the road salt issue in regard to the health of the environment and negative externalities associated with utilizing high levels of road salt (LGA, 2021). Elected officials were brought together to address this issue in New York. Alterations to the contents within the road salt mixtures has been assessed, in addition to implementation of enhanced and redesigned road plow blades and, maximization of the use of plows on roadways, and therefore reducing the need for such large amounts of road salt in addition to plowing (LGA, 2021). Perhaps other states such as Pennsylvania could begin to implement similar procedures to protect the waterways on which we rely for ecosystem services such as drinking water and recreation.

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