The Environmental Impacts of Rock Salt (Sodium Chloride) Application on the Sandy Hook-Staten Island Watershed and Sustainable Alternatives

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I. Abstract

Before the snow even begins to fall, the roadways and sidewalks turn shades of white. The culprit: rock salt. Sodium Chloride, or more commonly known as rock salt, has been used as a deicing agent since the 1940's. Countless studies have documented the benefits of applying rock salt or sodium chloride based brine solution as a deicer to roadways. The amount of annual road salt application has steadily increased since the 1960's, with now over twenty-two million tons of road salt used across the United States every year (PBS, 2014). Anthropogenic loading of sodium chloride into the rivers and streams from rock salt application have numerous detrimental impacts. Furthermore, data provided by USGS and interpreted using the Heinz equation show there are increased concentrations of sodium chloride during times of heavy rock salt application. Additionally the United States Geological Survey (USGS) data confirms the overall increasing concentration of sodium chloride in the Sandy Hook-Staten Island watershed over the past six decades. These fluctuations and generally increased sodium chloride concentrations can have severe impacts short-term and long-term effects to the watershed including impacts to water and soil quality, as well as wildlife and habitat health. Since the Sandy Hook-Staten Island watershed is home to federally- and state-listed endangered and threatened species, migratory species, and sensitive wetlands (NJ DEP, 2017; NY DEC, 2017; US Fish and Wildlife, 1997), these negative impacts should be taken seriously. Fortunately, there are many alternative options for urban road deicing as well as Best Management Practices (BMP) which can reduce environmental impacts while still keeping in mind the safety on the roadways during winter storms.

II. Introduction:

The purpose of this paper is to examine sodium chloride [NaCl] as an applied deicing agent within the Sandy Hook-Staten Island watershed. Understanding historical use, ionic and compound interactions in environmental media, and the impacts of sodium and chloride concentrations on the eco-system provide a base of knowledge in evaluating options to ensure the safety of the community.

This paper will examine specific conductivity and its correlation to sodium chloride in surface water samples as provided by USGS in the Sandy Hook-Staten Island Watershed over the past 60+ years. Data points will be divided and examined into three categories: Winter Months (November 1 through March 31), Post Winter Months (April 1 through June 30) and Pre Winter Months (July 1 through October 31). Data will also be analyzed as a whole to provide insight on application quantity trends of sodium chloride (i.e., specific conductivity) over the course of six decades.

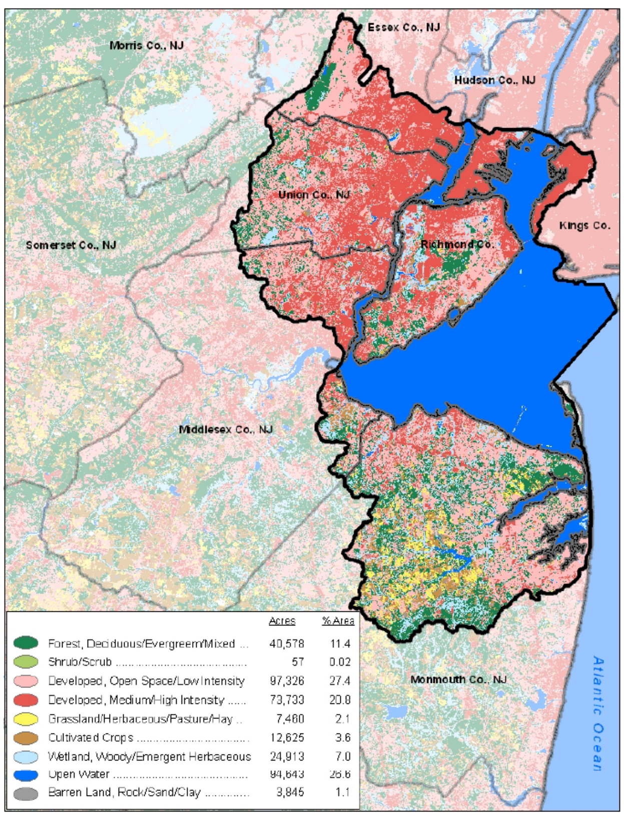
Two hypothesis will be examined in this report: 1) the greatest concentration of sodium chloride are documented in the winter months and the lowest concentrations are found in the months leading up to winter months, and 2) concentrations of sodium chloride are increasing over the past six decades. There are greatest concentrations of sodium chloride in surface water during winter months (November through March 31), due to the increase in rock salt application. Concentrations of sodium chloride (i.e. as measured through specific conductivity) will be persistently higher in "post winter months" and "pre winter months" will have the lowest concentrations. Application of rock salt will be highest during the winter months and will persist through post winter months until they are flushed out of the watershed/dispersed throughout the environment.

This paper will then examine the harmful side effects of increased concentrations of sodium chlorine in soils and surface waters to aquatic and terrestrial biota within the Sandy Hook-Staten

Island watershed. Finally, the paper will discuss viable alternative de-icing materials and techniques (BMPs) to reduce sodium chloride application demands and therefore reduce sodium chloride loading during winter months.

III. Sandy Hook-Staten Island Watershed Information:

The Sandy Hook-Staten Island Watershed is located in both New Jersey and New York. Some of the major water bodies located within the Sandy Hook-Staten Island Watershed include the Navasink River, Shrewsbury River, Hackensack River, and Hudson River. Only 12 percent of the land (or 42,283 acres) is within New York State with the remaining 88 percent (312,680 acres) is within New Jersey (USDA, 2011). The watershed occupies 354,963 acres and ranges in elevation from -7 to 646 feet above sea level (USDA, 2011). According to the 2000 US Census, a majority (96%) of the watershed is designated as an "urban" area (USDA, 2011). The land in the area is densely populated and highly developed due to the close proximity to New York City.



USDA, 2011

Within the watershed, there is very little commercial agriculture (USDA, 2011). There are approximately 350 farms, with most of them operating in New Jersey (USDA, 2011). The majority of the farms are smaller operations (i.e., under 50 acres) consisting of horse ranches, or soybean and hay crop farms in Monmouth County, NJ (USDA, 2011). Yet, where agriculture lacks, industry thrives. Due to the close proximity to the Atlantic Ocean and the numerous large rivers and bays, industrial and commercial operations boom within the watershed. Unfortunately, the USDA found that there are 32 major waterbodies that are either impaired or impacted negatively with pollutants (such as pesticides, heavy metals, PCBs, etc.) and have a designated use (i.e., aquatic life, recreation, drinking water, fishing, etc.) (USDA, 2011). The mixed urban, industrial, and commercial land use has arguably caused these negative impacts.

Humans are not the only species to utilize the watersheds resources. Over fifteen state threatened or endangered animals utilize the land within the watershed (USDA, 2011). Over 40 state threatened or endangered plants are found within the watershed (USDA, 2011). There are approximately 2,950 acres of New York State regulated wetlands in the NY portion of the watershed (USDA, 2011). Over 30 native fish species reside within the watershed boundaries (NANFA, 2016) with countless more in the nearby Atlantic Ocean.

With the majority (48.2%) of the area within the watershed is deemed “developed”. The remainder is either deemed Deciduous/Evergreen/Mixed Forest (11.4%), Shrub/Scrub (0.02%), Grassland/Herbaceous/Pasture/Hay (2.1%), Cultivated Crops (3.6%), Wetland (7%), and Barren Land (1.1%) (USDA, 2011). Additionally, a majority (35.3%) of the soils are documented as “well drained” (USDA, 2011). A total of 19.3 percent of the soils within the watershed are documented as either hydric or partially hydric soils (USDA, 2011). Due to the expansive size of the watershed, soil types can range from sand to silt, to clay throughout the region (NJDEP, 2016). Underlying the soils of the watershed is either the Cretaceous (sand, silt clay based), or Triassic (siltstone, shale, sandstone, and conglomerate based) bedrock (NJDEP, 2016).

Precipitation refers to all forms of water, liquid or solid, that fall from the atmosphere and reach the ground. Precipitation in this region is well distributed throughout the year (USDA, 2011).

Typically, the average annual precipitation within the watershed is between 44 inches and 50 inches per year (USDA, 2011), some of which consists of snow and sleet. On average the months of January, February, March, November, and December have historically produced 96.55 percent of the significant winter storms (snow and sleet) since 1956 (NOAA, 2016). Additionally, residual moisture can refreeze if temperatures fall below the freezing point of 32ºF. Winter storm events and below freezing temperatures can create hazardous conditions for drivers throughout the region. According to the U.S. Department of Transportation Federal Highway Administration, more than 70 percent of the U.S. population lives in regions receiving more than 5 inches of snow per year (Labashosky, 2015). Over 1,300 people are killed and 15,000 injured annually from automobile related collision on snowy and icy roadways (Labashosky, 2015).

IV. Historical and current use of NaCl:

Before deicing materials were ever applied to the nation's roads, snow plowing and abrasives such as sand and cinders were used to reduce road hazards after a winter event (Transportation Research Board, 1991). The use of deicers on roads was first documented in 1940 when the City of Detroit, Michigan used salt on roadways (Labashosky, 2015). During the winter of 1941-1942, New Hampshire was the first state to create a policy for salt application (Transportation Research Board, 1991). That year, a total of 5,000 tons of salt was spread on the nations roadways (Transportation Research Board, 1991). By 1955, 1 million tons of salt was being applied to the streets annually throughout the nation increasing to 10 million tons by 1970 (Transportation

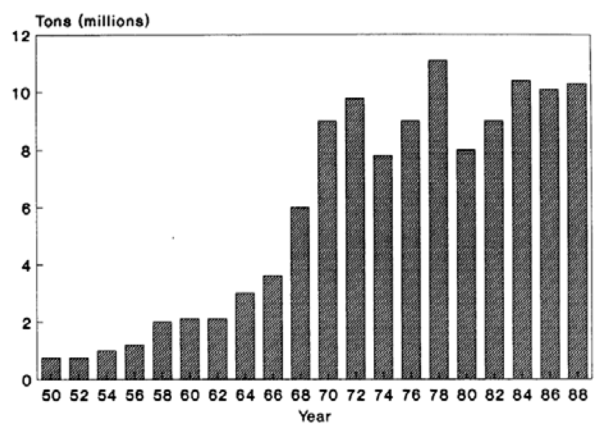


FIGURE 2-1 Trends in highway salt use, 1950–1988 (source: Salt Institute).

Figure 1 - Transportation Research Board, 1991

Research Board, 1991). The amount of road salt used annually has steadily increased. In the United States from 2005-2009 an average of 23 million tons of salt were applied to our roads, parking lots, sidewalks and driveways each year (New Hampshire Department of Environmental Services, 2011).

Currently, New Jersey Department of Transportation (NJ DOT) applies approximately 150 pounds per lane-mile of salt as a basis for spreading operations (NJ DOT email correspondence, 2016). The NJ DOT maintains 13,341 lane-miles of highways in the state of New Jersey (NJ DOT, 2016). New Jersey has 68 salt storage areas statewide with 227,986 tons of untreated salt storage, 716,402 gallons of liquid calcium, and 413,603 gallons of brine solution (NJ DOT, 2016). New York State Department of Transportation (NYS DOT) uses an average 800,000 tons of salt, 200,000 gallons of liquid (calcium or magnesium) chloride, one million gallons of salt brine, and 9,000 tons of abrasives on New York State maintained roads (NYS DOT, 2016). Application quantity and the regularity of salt application are typically highest on multi-lane, high speed roads such as interstates and freeways compared with lower volume, single-lane local roads in small towns (Eimers, et al. 2015).

In addition to the deicers applied to the roads, private properties (i.e., homes and businesses) also apply deicers to sidewalks, driveways, parking lots, and other privately maintained roadways. A majority of the materials and solutions that are applied before, during, and after winter storm events consist of sodium chloride due to its low costs and ease of obtaining (Eimers, et al., 2015). In the more recent history of the 60+ years of anthropogenic loading of sodium chloride into the environment, a significant amount of research has been compiled on how these solutions react in the environment.

V. How Sodium Chloride [NaCl] reacts in the environment

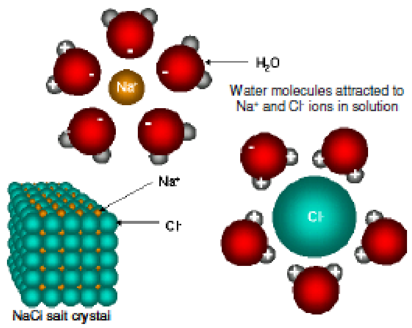


Figure 3-4. Graphical representation of Na and Cl ion effects on water. The NaCl crystal dissolves in water, which results in Na^+ and Cl^- ions in solution. The slightly negative charged oxygen atoms in the water are attracted to the Na and the slightly positive charged hydrogen atoms are attracted to the Cl.

Figure 2 - Kelting and Laxton, 2010.

Sodium chloride is a solute and therefore dissolves in water (Transportation Research Board, 1991). Two key points about solutes are: the solute must be in a liquid state to melt ice, and a solute that contributes more charge to solution will melt more ice at lower temperatures compared to a solute that contributes less charge to solution (Kelting and Laxson, 2010). The dissolution into water reduces the freezing point in proportion to the concentration of ions in solutions (Transportation Research Board, 1991). Sodium becomes an effective competitor for cation exchange when its concentration in the soil solution is increased. Road salt enters the soil solution and the Na^+ cation replaces other cations that are held in exchange.

Sodium chloride is very soluble in water and yields a large number of ions per unit weight (Ketcham, et al., 1996). It is especially effective as a freezing point depressant (Transportation Research Board, 1991). The differences in the amount of deicer needed to melt ice at a given temperatures is explained by the amount of charge contributed by the ions in solution (Kelting and Laxson, 2010). Since water is a polar molecule, the cations and anions contributed by the solute to the solution are attracted to the positive and negative poles of water molecules; this interferes with crystal lattice formation, (i.e., water to change from liquid to solid) (Kelting and Laxson, 2010). The more positive and negative charge contributed to the solution by the solute, the more water is attracted to the ions (Kelting and Laxson, 2010). Sodium chloride contributes 34 moles of charge (molc) per kilogram (kg) (Kelting and Laxson, 2010).

The first step in melting ice is to lower its freezing point. Moisture is required for the NaCl to work effectively since it is the main mechanism of deicing requires dissolution (Ketcham, et al., 1996). The applied salt dissolves into 40 percent sodium ions (Na^+) and 60 percent chloride ions (Cl^-) in the melting snow and ice (New Hampshire DES, 2010). Though solid or pre-wetted solid chemical solutions can be used as anti-icing treatments, there are advantages to use of liquids (brine solution) in small amounts for some conditions at pavement temperatures of about 5ºC (23ºF) and above (Ketcham, et al., 1996). This allows maintenance workers to uniformly place chemical over the pavement at efficient spreading speeds, as well as applying sodium chlorde onto dry pavement as a pre-storm treatment (Ketcham, et al., 1996).

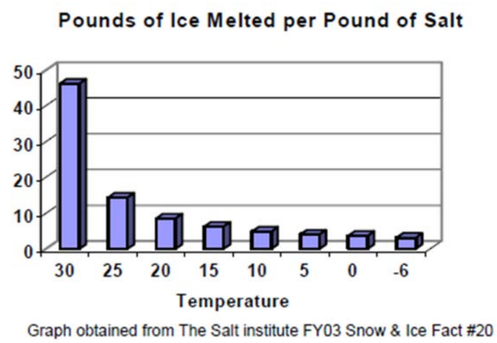


Figure 3 - New Hampshire Department of Environmental Services, 2011

The term "anti-icing" is typically used when discussing the application before snowfall has begun, preventing the bond between road way and snow or ice (Ketcham, et al., 1996). The term "de-icing" is used in reactive situations where snow or ice has already formed and the bond between pavements and snow or ice will need to be broken (Ketcham, et al., 1996). De-icing typically requires a greater amount of NaCl (i.e., a greater volume and amount of energy) in order to break the already crated bond (Ketcham, et al., 1996). In recent years, state maintenance groups have been shifting from reactive strategies to proactive strategies. Compared with traditional methods for snow and ice control (e.g., de-icing), anti-icing methods reduce the need for additional applications of chemicals and abrasives, decreased maintenance costs, and lower accident rates

(Fay, et al., 2009). Accurate weather forecasts are critical to a successful anti-icing program, as the road and pavement temperatures dictate the timing and rate for anti-icing applications (Fay, et al., 2009).

VI. The Problem:

Although there are numerous benefits for sodium chloride application (i.e., driving safety and reducing financial impacts of winter storms), the abundance of anthropogenic loading in the environment has several negative effects. Studies have shown that, in urbanized areas, about 95 percent of the chloride inputs to a watershed are from road and parking lot deicing (New Hampshire Department of Environmental Services, 2011). These unnatural concentrations of sodium chloride in the environment can wreak havoc on ecosystems by altering the soil and water composition and therefore impacting the biota and vegetation it sustains.

Once the deicer has been applied to the road, there are numerous ways that it can transition from the roadway to the surrounding environment (i.e., soil, groundwater, or surface water). The majority of deicer enters the environment via runoff by forming a solution and trickling off to low lying areas (Labashosky, 2015). Deicer material can dry after application and become airborne (i.e., dust) and vehicles can blow it off the road (Labashosky, 2015). Commonly, snowplows push the chemicals off the road onto the adjacent land (Labashosky, 2015). The deicers, which are highly persistent, can then accumulate in drainage ditches and storm water drains and ultimately enter lakes, rivers, streams, and soil (Labashosky, 2015).

Water resources have been significantly impacted by decades of sodium chloride application. Studies suggest (Godwin, et al., 2002) that the addition of sodium chloride from road salt application significantly changes the ionic composition of water (i.e., higher concentrations of Na^+ and Cl^-). The increased concentrations of chloride ions in water negatively impacts the overall health of the environment. Chloride is highly soluble, very mobile, and its density allows for it to settle to the bottom of a waterbody (New Hampshire NES, 2011). The transport of sodium in the environment is not as prominent as chloride due to ion exchange; however, this exchange can alter the soil chemistry by replacing and releasing nutrients such as calcium, magnesium and potassium into the groundwater and surface water (New Hampshire NES, 2011). This can lead to increased nutrient concentrations and affect the ability of the water to buffer acid deposition impacting the aquatic environment (New Hampshire NES, 2011). Additionally, there is evidence that sodium and chloride can mobilize heavy metals and increase concentrations of cadmium, zinc, copper, and lead (Bäckström, et al., 2003). The major mobilization mechanisms are ion exchange, lowered pH, chloride complex formation and possible colloid dispersion (Bäckström, et al., 2003).

Sodium chloride application immediately affects the nearby streams and rivers. Typically, the effects of NaCl are seen in aquatic habitats up to 1,500 meters from treated roadways (Andrews et al. 2008) but with substantial loading, and accumulation overtime, communities exceeding the 1,500 meter surface water pathway can be effected. Increases in sodium and chloride concentrations have been linked to lowered biodiversity of macro-invertebrates in streams, reduced densities of benthic organisms, and decreased biomass and richness in wetlands (Gibbs, 2008). Specifically, amphibians in all stages of life, are particularly sensitive to sodium and chloride concentration fluctuations (Gibbs, 2008). Amphibians sensitivity to sodium chloride is due to their highly permeable skin, which enables osmoregulation and respiration, and because their life cycle includes both aquatic and terrestrial stages (Kelting and Laxson, 2010). Water bodies (streams, vernal, ponds) located with 50 meters of major highways were at the greatest risk of being negatively impacted (Gibbs, 2008). Studies have shown that concentrations of chloride at levels above 230 mg/l is toxic to organisms adapted to freshwater (New Hampshire NES, 2011).

Over time, lakes can be significantly affected by increases in sodium chloride concentrations. Sodium and chloride concentrations in lakes, if high enough, can alter the salinity dynamics and seasonal mixing (Heinz, 2008 and Gibbs, 2008). The delayed or lack of seasonal mixing in lakes can impact the dissolved oxygen profiles and overall health of the lake (Heinz, 2008). During chemocline, phosphorus is released from anoxic sediments into the water above at much higher rates than when the sediments are well aerated (Heinz, 2008). With longer anoxic periods, more phosphorus could be released from the sediments therefore stimulating algal blooms in the surface mixed layer when the lake finally overturns (Heinz, 2008). Anoxic zone could be increased reducing the inhabitable space for fish in the lake. Although there are numerous factors which affect chemocline in lakes (i.e., climate, solar radiance, wind direction and speed), it is important to examine all possible effects of sodium chloride within the environment (Heinz, 2008).

Contaminated surface water can percolate through the soil and into aquifers. It has been documented that there are increasing concentrations of Na^+ and Cl^- in shallow groundwater in urban areas due to decades of excessive deicing material application (Howard, 1993). Studies have shown that less than 50 percent of applied sodium and chloride are being naturally removed from subsurface waters each year, and therefore, sodium and chloride is exponentially accumulating in groundwaters (Howard, 1993). A major concern rising from documented increases in sodium and chloride concentrations in both surface water and groundwater is the human health risk it poses (Transportation Research Board, 1991). Although water resources used for potable purposed typically goes through treatment, private well operators may not be educated on the possible risks and necessary monitoring required to ensure safe drinking water.

Soils are significantly impacted by deicing material road application. Typically, the most predominately effected soil is located within 15 feet of the pavements edge due to its ability of long-term accumulation (Transportation Research Board, 1991). Sodium chloride in the soil can affect soil structure, increase soil density, and reduce permeability, moisture retention, and fertility. Hydrogen ions (H^+) displace Na^+ leading to an increased pH limiting the availability of nutrients (Mn, Fe, Zn, Bo). Sodium ions (Na^+) penetrating the soil as sodium chloride may replace calcium (Ca^{2+}), potassium (K), and magnesium (Mg^{2+}) ions associated with soil structure. These replacements are documented by the increasing amount of calcium, magnesium, and potassium observed in the soil column discharge solutions over time (Sun, 2010). Soil types and characteristics can greatly affect interactions with the environmental community around it. The retention rate of sodium and chloride in soils varies from basin to basin due to different soil characteristics, including their inconstant cation exchange capacity (Sun, 2010).

Terrestrial organisms and vegetation are also impacted by sodium chloride. The principal impact of NaCl would be on vegetation (Robidoux and Delisle, 1999). Roadside vegetation can be injured by salt concentrations, but mainly through the exposure to chloride (Transportation Research Board, 1991). Chloride toxicity inhibits growth, browning of leaves, and even premature plant death (Transportation Research Board, 1991). Toxicological studies on terrestrial organisms are important since they are the primary receptors (Robidoux and Delisle, 1999). Numerous studies (Robidoux and Delisle, 1999) have shown that deicers were relatively toxic to assay organisms (plants and earthworms) and acute toxic effects on macrphyte germination were similar (Robidoux and Delisle, 1999). Seed germination may be inhibited by the presence of Cl^- ions which disturb cellular regulation mechanisms (Robidoux and Delisle, 1999). There is evidence that reduced toxicity to soil organisms and plants may be associated with the adsorption of sodium chloride to organic matter (Robidoux and Delisle, 1999); therefore, it is important to understand how a specific soil interacts with the concentrations of NaCl.

The Sandy Hook-Staten Island watershed is no exception to the impacts of sodium chloride road application. If anything, the effects are exacerbated due to the dense population and urbanization throughout the watershed boundaries. Currently, New Jersey is home to 20 federally endangered species, and one federally threatened species (NJ DEP, 2017). Additionally, New Jersey has listed 31 state endangered species and 33 state threatened species (NJ DEP, 2017). The Sandy Hook-Staten Island watershed is home to five federally-list endangered species, three federally-listed threatened species, and numerous New Jersey and/or New York state-listed endangered and threatened species (US Fish and Wildlife, 1997; NJ DEP, 2017; NY DEC, 2017). Furthermore, there are numerous state-listed species of special concern, such as rare-plants and migratory species (US Fish and Wildlife, 1997). With nearly 26% of the watershed covered on open water and 7% of the land designated as wetlands (USDA, 2011), a majority of the watershed consists of sensitive environments. Along the shoreline of the bay are important fish nursery areas, foraging and nesting areas for birds and reptiles, and migratory and wintering habitats for various species (US Fish and Wildlife, 1997). This estuarine environment is known for shellfish and marine, estuarine, and anadromous fish (US Fish and Wildlife, 1997). The coastal region is also regionally significant for migratory and wintering waterfowl concentrations (US Fish and Wildlife, 1997).

Unfortunately, there are no natural methods to remove sodium or chloride from the environment, and therefore, sodium chloride is extremely persistent. They do not “biodegrade”, do not easily precipitate (react with other ions to form a solid), do not volatilize, are not involved in biological processes, and do not absorb significantly on mineral surfaces (Michigan Dept. of Transportation, 1993). Typically, a majority of the concentrations will be diluted over time and flushed from the system. Still, as discussed before, sodium chloride can and has accumulated in soils and water, especially in urban areas where application is a necessity. Keeping this in mind, it is important to think forward to the future and examine alternative deicing materials and methods.

VII. Analysis:

In order to understand the effects of sodium chloride within the Sandy Hook-Staten Island watershed, this paper will examine surface water data over six decades within the aforementioned watershed. By observing changes in the surface waters of the region, we can better understand the scale of possible impacts and better prevent negative side-effects.

Materials & Methods:

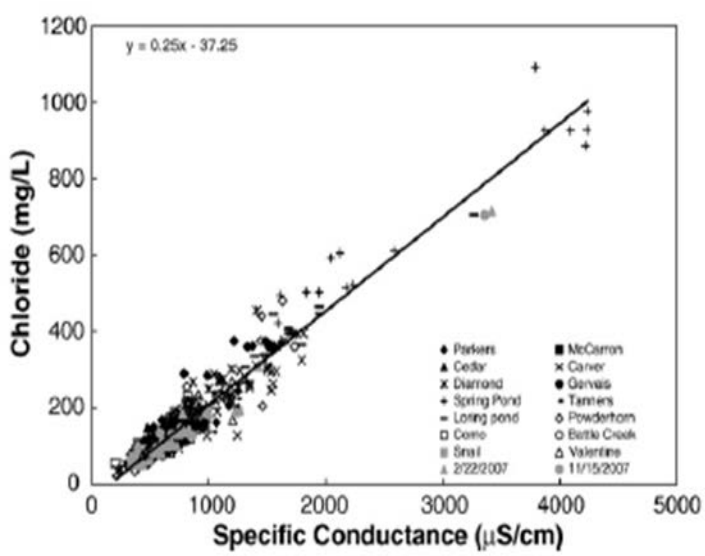


Fig. 3 – Relationship between chloride and specific conductance.

Figure 4 - Stefan G. Heinz, 2008.

A strong correlation of specific conductance with sodium chloride concentrations has been documented in numerous cited reference documents (Miller, 1922; Heinz, 2008). Since chloride is a conservative ion and has few natural sources in the environment, it is a good indicator of road salt (NaCl) (Heinz, 2008). In previous reports, an equation was created to convert specific conductance (µS/cm) into chloride concentration (mg/L): $[Cl^-] = 0.25*SC - 37.25$ (Heinz, 2008). This equation was created using historical analytical information from surface water samples analyzed for chloride, sodium, potassium, calcium, and magnesium. A linear relationship was created from this data in respect to specific conductance (Heinz, 2008).

This paper examines surface water data from over 70 surface water bodies within the Sandy Hook-Staten Island watershed provided by (USGS) collected from New Jersey Department of Environmental Protection (NJ DEP) and various departments within USGS. A total of 1,190 data points (i.e., specific conductance values of surface water samples) were examined between February 1952 and December 2016. Using the Heinz equation (Heinz, 2008), the specific conductivity values of surface water samples will provide estimated concentrations of chloride in the watershed throughout the six decades. The estimated chloride concentrations will show the approximate sodium chloride concentrations in surface waters. This information will provide insight on rock salt application annually and over six decades. Further, this information can extrapolate future NaCl concentration in surface water with current trends.

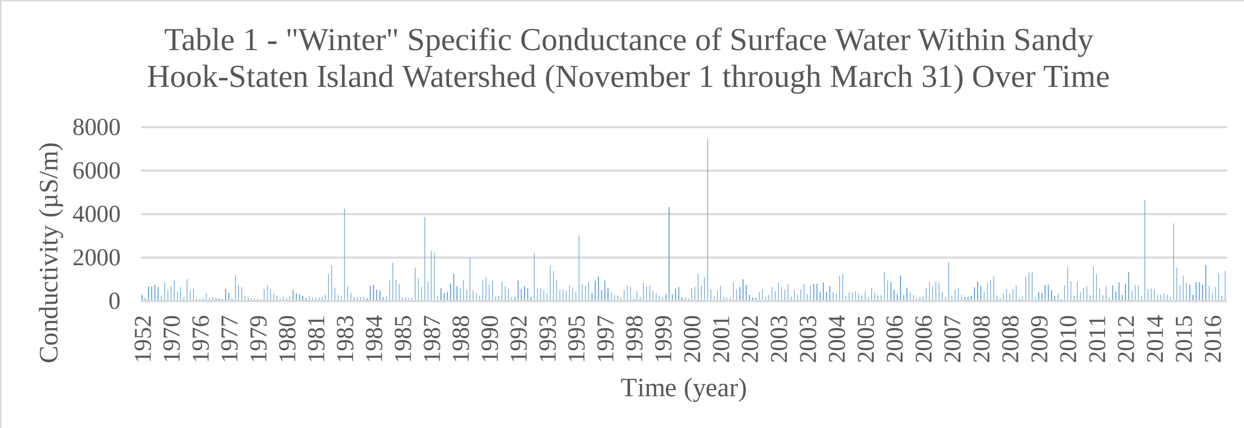
The data points will be divided into three categories: Winter Months, Post Winter Months, and Pre Winter Months. This data analysis will provide insight on annual fluctuations of rock salt application within the watershed surface waters. Data will also be analyzed to provide insight on application quantity trends of sodium chloride (i.e., specific conductivity) over six decades. A similar approach will be used to associate specific conductivity concentrations into chloride ion concentrations which will provide insight to approximate sodium chloride concentrations. This data analysis will show long term fluctuations of sodium chloride and possible accumulations in the watershed.

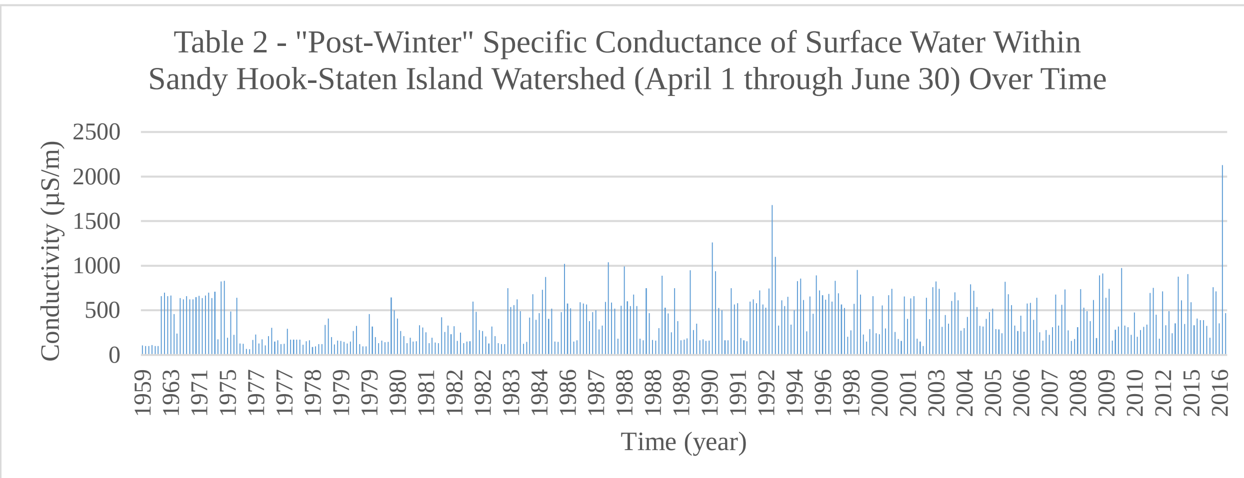
Hypothesis: The hypothesis of the analytical analysis is that the greatest concentrations of sodium chloride in surface waters are during winter months and the lowest concentrations in surface waters are during Pre-Winter months. This hypothesis is based off the fact that sodium chloride application is greatest during winter months due to heavy application of rock salt during winter storm events and when below freezing temperatures occur most frequently. It is hypothesized that the sodium chloride will persist from the winter months through post winter months until they are flushed out of the watershed and are dispersed throughout the environment.

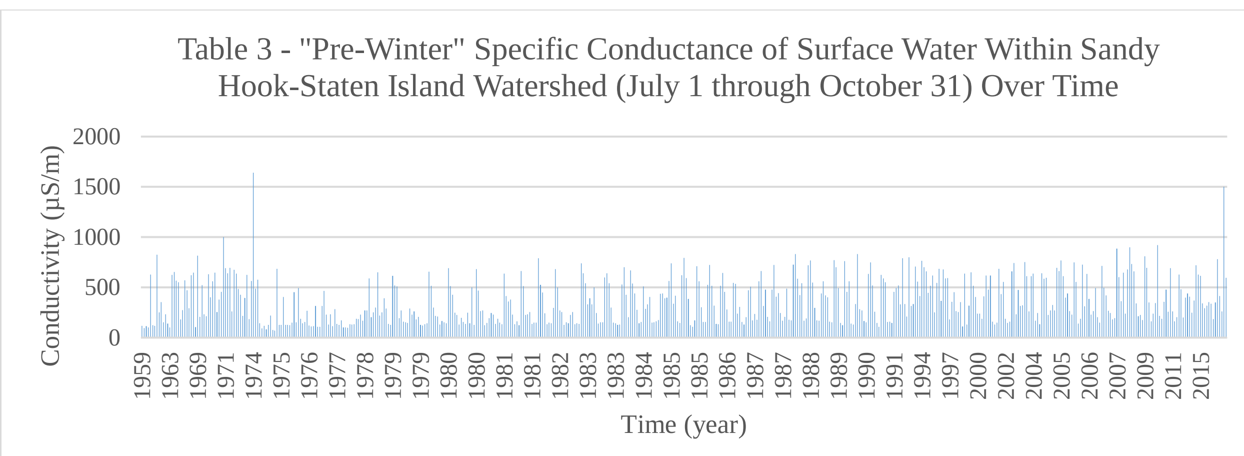
Additionally, this paper hypothesizes that there are increase concentrations of NaCl in surface water within the watershed over six decades due to rock salt applications. Literature has documented the increased dependency of rock salt during winter storm events and below freezing temperatures to ensure the safety of drivers and pedestrians. This increase reliance of rock salt increases the application frequency and rates. Cost effective pricing and easy access to rock salt allows for more to be input into the environment.

Results: The analysis of the USGS provided data over six decades confirms both proposed hypotheses that 1) there are greater concentrations of sodium chloride in surface waters during the winter months and that concentrations gradually decrease over time, and 2) there are overall higher average annual concentrations of sodium chloride in surfaces water over time due to anthropogenic activities.

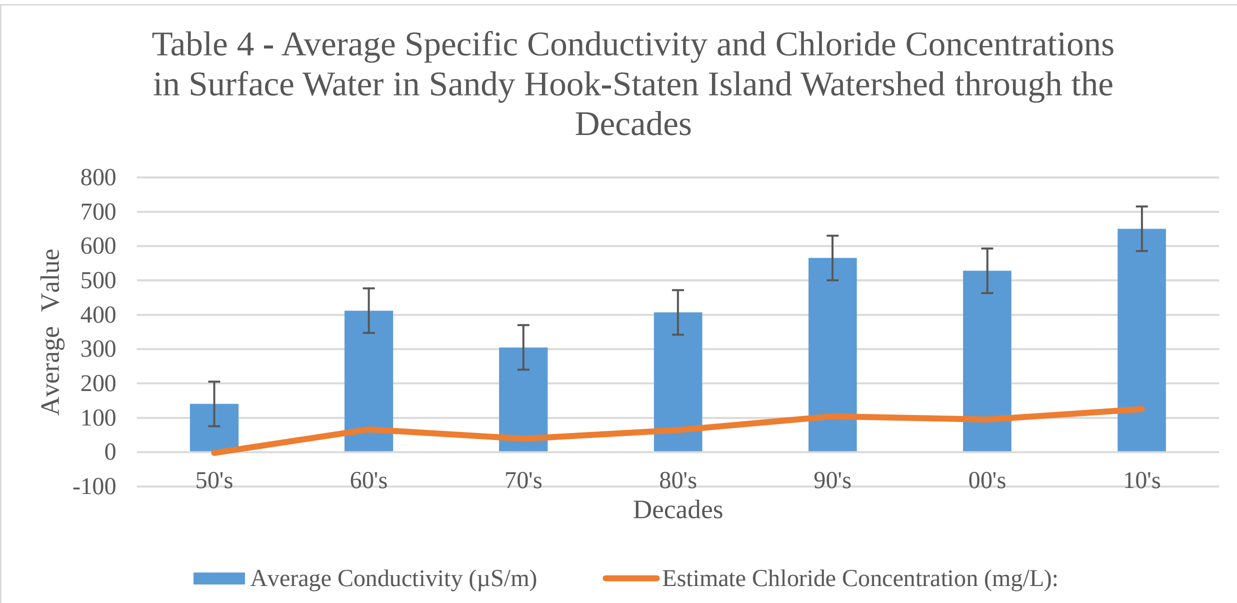
The specific conductivity of surface water samples confirms the increased presence of sodium chloride throughout the Sandy Hook-Staten Island watershed. Specific conductivity, an indicator of chloride ions in solution, shows that during winter months (i.e., November 1 through March 31), there are higher average concentrations than when compared to the other two data sets (i.e., Post-Winter and Pre-Winter) (see Figures 1, 2 and 3). Furthermore, the lowest measurements of specific conductivity are documented in "Pre-Winter" months, which have not been exposed to rock salt application for many months. The reduced concentrations are likely due to the reduction or lack of rock salt application as well as natural flushing and dilution from rainfall and tidal activity.







Additionally, over six decades, specific conductivity measurements have increased which demonstrate increases in average sodium chloride in surface waters (as seen Table 4). This is likely due to a combination of increases in the volume of rock salt application as well as accumulation over the years. The decreased cost and easy access to rock salt over the decades has proven to increase the amount of volume that is applied. Additionally, urban areas are expanding, resulting in additional roads, parking lots, apartment complexes, stores, and homes. All of these entities are encouraged (if not legally responsible) to provide safe roads and walkways. These urban areas demand additional safety measures, especially since there are countless studies showing the safety benefits of rock salt application during winter storm events (Labashosky, 2015; Stone, 2010; Fay, 2009; Transportation Board, 1991).



Unfortunately, there are numerous variables that are not evaluated in the analytical assessment and discussion. Firstly, data collected over six decades will naturally have variables, especially when they are collected from different entities, using different methods of collection and field and laboratory analysis. Furthermore, technology and lab analysis accuracy has significantly improved; these considerations should be evaluated during all analytical analysis when examining historical data.

The urban landscape throughout the Sandy Hook- Staten Island watershed also contributes additional variables. Other anthropogenic sources of sodium or chloride from commercial and industrial entities may contribute to the fluctuating and overall sodium chloride concentrations and changes in the specific conductivity. Although rock salt has been well documented as the majority non-point source in other studies throughout the United States and Canada, the densely urban setting should be considered as a variable that was not controlled in this examination. Although the quantity, rate, and frequency of application is well documented for interstate, state, and county roadways, the exact quantities applied by private entities is difficult to capture. These private entities not quantified in this report include private property owners, commercial properties, and private communities. Fortunately, this report does not discriminate against the origination of the rock salt (private versus public/federal entities), yet reports and examines the total quantity.

Finally, although numerous studies have shown a strong correlation of specific conductivity to chlorine concentrations and therefore sodium chloride concentrations (applied as rock salt), the analysis and data manipulation is not an exact transposition. This correlation coefficients between specific conductivity and the individual ionic concentrations of chloride and sodium were 0.99 and 0.97, respectively (Heinz, 2008). Heinz's correlation proved $R^2 = 0.95$ between specific conductivity and chloride concentration. Unfortunately, the Heinz equation, used in the data interpretation does not allow for error. Furthermore, the same study noted a less confident sodium concentration correlation with a lower R^2 value and was slightly less reliable in demonstrating accurate estimates of sodium ions in solution (Heinz, 2008).

Conclusions: The analytical analysis of data within the Sandy Hook-Staten Island watershed further demonstrate the continuous impacts of rock salt application as a deicer agent. The significant increases of sodium chloride in winter months and slow decrease over time due are likely directly due to anthropogenic rock salt application. Additionally, the trend of increasing concentrations over the past six decades validates the need to examine alternative options and Best Management Practices (BMP) in order to reduce sodium chloride concentrations from further impacting the environment.

Significantly important effects of sodium chloride within the Sandy Hook-Staten Island watershed include soil and water health, and potential eco-system impacts. The watershed is especially prone to soil and water health impacts due to its dense, urban development. With significant industrial and commercial presence throughout the watershed, the loading of anthropogenic contaminants is much greater than areas with less development. A slight variation in water or soil quality can significantly alter and offset whole ecosystems. Aquatic, terrestrial, wetlands, and other sensitive environments are utilized for mating, breeding, and feeding of countless species throughout the watershed. Since the Sandy Hook-Staten Island watershed is home to numerous federally- and state-listed endangered and threatened species, various migratory species, and sensitive wetland environments (NJ DEP, 2017; NY DEC, 2017; US Fish and Wildlife, 1997), these negative impacts should be considered. By understanding these specific effects on the environment, it encourages us to find less impactful "solutions".

VIII. Alternative options & BMPs –

This paper has gone into extensive detail as to how sodium chloride reacts in the environment, and that there is clearly an abundance of anthropogenic NaCl dispersed in our environment year after year. Luckily, there are other options of deicing materials that are slowly coming into the spotlight for their efficiency. Unfortunately, many of these options are not as readily available and currently are not as cost effective as the conventionally used "rock salt". As governmental policy makers, communities, and environmental activists become more educated and aware of the harmful effects of over applied sodium chloride, alternative options and smarter application techniques are becoming more widely used. This paper will discuss alternative deicing materials as well as BMPs to reduce the application of sodium chloride as a deicer into the environment.

Alternative Options:

There are countless options of alterative resources that can be used as anti-icing or deicing materials. They range from the unorthodox (beet juice and molasses) to the synthetic (Urea) to more conventionally used (variations of sodium and chlorides). This paper will discuss the five more frequently and widely available materials used in the United States: Calcium Chloride (CaCl2), Magnesium Chloride (MgCl2), Calcium Magnesium Acetate (CMA), and Potassium Acetate (KAc), and Urea.

Calcium Chloride ($CaCl_2$): (Ketcham, et al., 1996) CaCl2 is the second most commonly used deicing compound and has a practical melting point of -20°F (New Hampshire DES, 2010). Chlorine may form complexes with heavy metals that actually increase their mobility in groundwater (Kelting and Laxson, 2010). The cation exchange is similar to NaCl which can increase the mobility of heavy metals (Kelting and Laxson, 2010). Chlorine loading, similarly seen in NaCl and $CaCl_2$ use, is possible in smaller water bodies (Kelting and Laxson, 2010). Although wildlife stress is not evident, roadside vegetative stress has been seen due to osmotic processes (Kelting and Laxson, 2010). Additionally, $CaCl_2$ is over 3x more expensive than typical road salt (Kelting and Laxson, 2010).

Magnesium Chloride ($MgCl_2$): (Ketcham, et al., 1996) Magnesium chloride has a similar effect in the environment as $CaCl_2$. $MgCl_2$ has a practical melting temperature of 5°F (Kelting and

Laxson, 2010). Osmotic processes can stress vegetation and chloride can release heavy metals into solution easier due to cation exchange actions (Kelting and Laxson, 2010).

Calcium Magnesium Acetate (CMA): (Ketcham, et al., 1996) CMA has a practical melt temperature is 20°F (New Hampshire DES, 2010). CMA has minimal vegetative or wildlife adverse effects (Kelting and Laxson, 2010). Although calcium and Magnesium actually improve soil structure, similar to sodium and chloride, it has the potential to exchange with heavy metal ions in the soil and release them into the environment (Kelting and Laxson, 2010). These heavy metals can move throughout the soil profile and into groundwater (Kelting and Laxson, 2010). Additionally, acetate degradation can decrease the amount of dissolved oxygen in surface waters, especially in smaller water bodies (Kelting and Laxson, 2010). This reduce dissolved oxygen can significantly reduce the health of these ecosystems (Kelting and Laxson, 2010). It is more expensive than rock salt (approximately 35x more expensive) but a full cost analysis may show that is it an economically viable choice given its numerous benefits (Kelting and Laxson, 2010; New Hampshire DES, 2010). Many states use CMA in environmentally sensitive areas and on bridges prone to salt corrosion (New Hampshire DES, 2010).

Potassium Acetate (KAc): (Ketcham, et al., 1996) has a practical melting temperature of -15°F and is biodegradable and non-corrosive (New Hampshire DES, 2010). It can cause slick road conditions if applied in excess and can lower dissolved oxygen levels in nearby waterbodies (New Hampshire DES, 2010). KAc is relatively non-corrosive (New Hampshire DES, 2010).

Urea (CH_4N_2O): Urea has a practical melting temperature of -15°F is only effective above 15°F but is relatively cost efficient (1x higher than NaCl costs) (Kelly, et al., 2010; New Hampshire DES, 2010). An abundance of Urea in the environment can cause eutrophication in nearby water bodies due to its nitrogen content (Kelly, et al., 2010). Unfortunately, urea breaks down quickly into ammonia and can be easily released into nearby waterbodies via runoff (New Hampshire DES, 2010).

As shown in Table 5, the costs of deicers vary significantly, with sodium chloride being the cheapest (~$42/ton) and CMA being the most expensive ($1,492/ton). Being that money drives many decisions, it is important to examine the overall effectiveness and the costs associated with application (i.e., cost of material, ease of deployment, environmental costs).

Table 5-1. Properties, usage, and cost information for chloride salts and acetate deicers.

Material	Chemical Formula	Forms Used	Eutectic Temperature (°F) and concentration (%)		Annual Usage (tons)†	Median Cost (USD) per Ton‡
Sodium chloride	NaCl	Solid and brine	-5.8	23.3	4,773,000	$42
Calcium chloride	$CaCl_2$	Solid and brine	-60.0	29.8	47,679	$140
Magnesium chloride	$MgCl_2$	Solid and brine	-28.0	21.6	149,724	$111
Calcium Magnesium Acetate	CaMgAc	Liquid and solid	-17.5	32.5	21,817	$1,492
Potassium Acetate	KAc	Liquid	-76.0	49.0	56	$1,166

† North America, from TRB, 2007; ‡ 2003 values adjusted to 2009 based on CPI

Table 5 - Kelting and Laxton, 2010.

Best Management Practices:

As discussed earlier in this paper, there are two ways to reduce the hazards of ice and snow on the road ways: 1) anti-icing and 2) de-icing. It is important to understand the conditions required in order to be most efficient in the type of material, timing and placement of application. Temperature is a driver of what deicing material is most efficient. As seen in Figure 5, the eutectic temperature (or the temperature at which a particular eutectic mixture freezes or melts) varies between materials (Ketcham, et al., 1996). Once the temperature falls below the eutectic temperature of the material, it no longer has deicing capabilities. Additionally, the lower the temperature of the air and surface, the less soluble the material will be (Ketcham, et al., 1996). Of the previously examined deicing materials, sodium chloride has the highest eutectic temperatures, which means it has a limited ability of deicing, especially in regions that have frequently are lower than -5.8ºF. Potassium Acetate (KAc) has the lowest eutectic temperature of -76.0ºF, followed by calcium chloride ($CaCl_2$) of -60.0ºF.

Road conditions are essential to make critical decisions on material quantity, frequency, and method of application. Although the upfront cost of installing and operating accurate weather monitoring systems may be pricey, it can provide valuable information on the best timing, material, and volume to apply to be most efficient. The use of monitoring equipment of current weather conditions can ensure proper application (especially which type of deicing material should be used at certain temperatures). Currently, the NJ DOT maintains 41 remote roadway weather sensing stations (RWIS) to help keep crews informed of road conditions on the state highway system (NJ DOT, 2016).

Understanding road and forecasting future environmental conditions is essential for efficient use of deicing materials. Since moisture is required for the materials to become into solution, road conditions will determine how the material should be applied (either in a pre-mixed solution or in solid form). Pre-wetting the solid form of sodium chloride will allow it to stick to the road surface and reduce the amount that bounces, splashes, or is kicked off the road (Kelly, et al., 2010). Brine solutions are extremely effective when used as an anti-ice method or during permitting conditions (Kelly, et al., 2010).

Other easy, non-technical, BMPs that can be implemented to reduce anthropogenic sodium chloride in the environment include the following:

1) Do not overfill application equipment - Only put the amount of salt in your truck that you need for your route. Studies have shown that 20% less salt is used if the exact amount of salt is loaded. Drivers tend to use what they load, which can often be more than is needed. (Kelly, et al., 2010)
2) Properly store stockpiles NaCl in covered areas with adequate containment such as curbing or berms on impermeable surfaces. Do not build storage areas in designated wellhead protection areas or in regions within a 100-year of less storm level. (NJDEP, 2004)
3) Calibrate spreading equipment frequently to ensure the proper amount of material is being applied over the specific surface area. Installing plow truck with newer technology that allows for more accurate quantity application. (Kelly, et al., 2010)
4) Maintain good housekeeping procedures or NaCl storage facilities and spreading equipment. Preventing spills of material during loading and storage of material is essential to reduce runoff. The immediate cleanup of any spills can reduce negative impacts. (NJDEP, 2004)
5) Education and training on efficient application techniques. Provide sufficient opportunities for the annual training and continuous learning of winter maintenance BMPs. (Fay, 2009)
6) Application of abrasives such as sand can also be used to enhance traction control on roadways. Although they do not significantly reduce ice formation, abrasives will provide additional traction. (Michigan DOT, 1993)

IX. Conclusion

Although sodium chloride is an effective way to protect urban areas during winter storms and freezing weather events, it has numerous negative impacts on the surrounding environment, especially within the Sandy Hook-Staten Island watershed. The exponential increase of anthropogenic sodium chloride application, in the form of rock salt, to roadways has subsequently increased NaCl concentrations (as evident through extrapolation of specific conductivity data) in surface waters from the average 140 µS/m in the 1950's to over 650 µS/m by the 2010's. This interaction between sodium and chloride with terrestrial and aquatic ecosystems alters the naturally occurring seasonal fluctuations. Although sodium chloride concentrations stabilize post winter, the continual loading can and will negatively impact these sensitive ecosystems.

Fortunately, there are alternatives and best management practices available in order to reduce the use of sodium chloride as a deicer. Calcium Chloride ($CaCl_2$), Magnesium Chloride ($MgCl_2$), Calcium Magnesium Acetate (CMA), and Potassium Acetate (KAc), and Urea are all alternative options that, if used correctly, can reduce the amount of sodium and chloride loading. These deicing agents, if used in conjunction with Best Management Practices, will protect ecosystems with dense urbanized areas, like the Sandy Hook-Staten Island watershed, from future impacts.

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