AN EVALUATION OF CHLORIDE MOVEMENT AT A RAIN GARDEN

By

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NOMENCLATURE

SCM	Stormwater Control Measure
ppm	parts per million
ppt	parts per thousand
BMP	Best Management Practice
Na^+	Sodium Ion
Ca^{2+}	Calcium Ion
Mg^{2+}	Magnesium Ion
H^+	Hydrogen Ion
mg/g	milligrams/ gram
mg/L	milligrams/ liter
g/cm^3	grams/ cubic centimeter
GIS	Geographic Information System
TSS	Total Suspended Solids
TDS	Total Dissolved Solids
µS/cm	microsiemens/ centimeter
°C	Degrees Celsius
°F	Degrees Fahrenheit
S	Salinity
PSU	Practical Salinity Unit
CSW	Constructed Stormwater Wetland

ABSTRACT

Every year thousands of tons of rock salt are used as a deicing agent in the winter and spring months to control snow and ice in the state of Pennsylvania. Although chloride ions are naturally occurring in the environment, this additional chloride becomes part of the water system once the snow and ice melt. Rain gardens are increasingly being used to control stormwater, divert runoff, and allow infiltration and evapotranspiration to restore the hydrologic cycle that was disrupted by development. In the winter months, however, rain gardens concentrate chlorides and there is concern about the effect these chlorides may have on the rain garden soils and groundwater beneath these infiltration features. To determine if the chloride concentrations in the rain garden soils and the groundwater water beneath a rain garden at Villanova University were elevated, conductivity was measured. Surface water samples were taken of inflow and ponding water, conductivity probes at various depths were installed in the soil, and groundwater probes were installed to monitor the vertical movement of chlorides. Results indicate that chloride ions are elevated during winter and spring months, as evidenced by spikes in conductivity in both soil and groundwater. The elevated levels remain days to months after the deicing season, and the chloride concentrations in the soil do not completely return to baseline conditions, even in the summer. Groundwater conductivity values were evaluated and results show a seasonal chloride plume peaking in the summer months.

A comparison of the Villanova University Constructed Stormwater wetlands was done in contrast to the rain garden. An assessment of how the chloride ions move and are retained in the different stormwater control measures was determined and last, it was determined how long it

takes a chloride ion to move, either through the rain garden to the groundwater table and then to the nearest water body or through the wetland to its nearest water body.

Chapter 1. Introduction

Management of stormwater is a growing concern in urban and suburban environments (Dietz and Clausen 2005; Heasom et al. 2006). Impervious areas such as roadways, parking lots, and buildings prevent rainfall from infiltrating into the ground, which results in increased runoff. In areas where the runoff flows into creeks and streams, the surplus water creates high velocities that can erode natural creek banks. The runoff also includes pollutants that have accumulated on the impervious surfaces like heavy metals, nutrients like phosphate and / or nitrites, and chlorides (Dietz and Clausen 2005). Stormwater control measures (SCMs) manage stormwater by collecting the runoff and infiltrating it into the soil and groundwater to restore the natural hydrologic cycle. In addition, SCMs have been shown to be effective at controlling pollutants (Hunt et al. 2009). The contaminant of concern for this research is chloride related to deicing salt.

Deicing salt is often used on roadways and walkways to melt snow or ice hazards. Deicing salt is readily available and inexpensive. The salt melts the ice and snow when the temperature is above a certain level; however, it is not effective below 0°C (Ramakrishna and Viraraghavan 2005). Unfortunately, the excessive use of salts can be harmful to cars and to the environment. Salt leaches from impervious areas into surface water, soil, and groundwater. This leaching changes the salinity of the water; while salty water is slightly unpleasant for people, it can be life threatening to the organisms that require aquatic systems to survive (Commonwealth of Pennsylvania 2010).

Chloride is considered to be a useful, conservative tracer in water bodies to help determine residence time as it is very soluble and mobile. A conservative tracer, such as chloride, does not have natural process that break down, metabolize, or are removed from the environment. These means chloride ions are a greater concern than sodium or other ions entering the water system. Because of road salt, it is estimated that 40 percent of urban streams in the country have chloride levels that exceed safe guidelines for aquatic life (Stromberg 2014).

This research evaluates the movement of chlorides through a rain garden on Villanova University's campus. This work will examine how chloride ions move from impervious surfaces by combining with stormwater/precipitation, collecting in surface water, infiltrating through soil, and finally releasing into groundwater. The lag times between incoming and exiting chloride ions will be evaluated by looking at the changes in conductivity readings taken from the surface water, soil, and groundwater. A nearby site was selected to provide baseline soil conductivity values.

Chapter 2. Literature Review

2.1. Salinity and Chloride Introduction

Salinity is the measure of salts in water or soil. Sodium chloride is the salt that is most associated with salinity, but salts that affect surface water, soil, and groundwater are a combination of sodium, calcium, potassium, magnesium chlorides, nitrates, bicarbonates, and carbonates (Table 2.1).

Table 2.1. Different Types of Salt (from Provin and Pitt 2001)

Common Name	Chemical Name	Chemical Formula
Table Salt	Sodium chloride	$NaCl$
Glauberis Salt	Sodium sulfate	Na_2SO_4
Baking Soda	Sodium bicarbonate	$NaHCO_3$
Epsom Salt	Magnesium sulfate	$MgSO_4$
Gypsum	Calcium sulfate	$CaSO_4 \cdot 2H_2O$
Street Salt	Calcium chloride	$CaCl_2 \cdot 2H_2O$
Muriate of Potash	Potassium chloride	KCl
Muriate of Sulfate	Potassium sulfate	K_2SO_4

Salt naturally occurs in surface water, soil, and groundwater. Salt is added to the water system in a variety of ways including, but not limited to, water softeners, septic and sewage effluent, natural salt deposits, and agriculture (fertilizer and livestock) (Boutt et al. 2001; Nimiroski and Waldron 2002). A study of the different sources of sodium chloride into the East Branch of Wappinger Creek, NY showed that 91% of the sodium chloride input was from the salt used for deicing. Sewage and water softeners contributed 4% and 3%, respectively and only 2% was from atmospheric deposition and rock weathering (Kelly et al. 2008). The flow chart depicted in Figure 2.1 shows the variety of pathways that deicing chemicals can move and their adverse effects. The focus of this thesis is on salt pertaining to a deicing or anti-icing agent, specifically sodium chloride, in cold weather and climates.

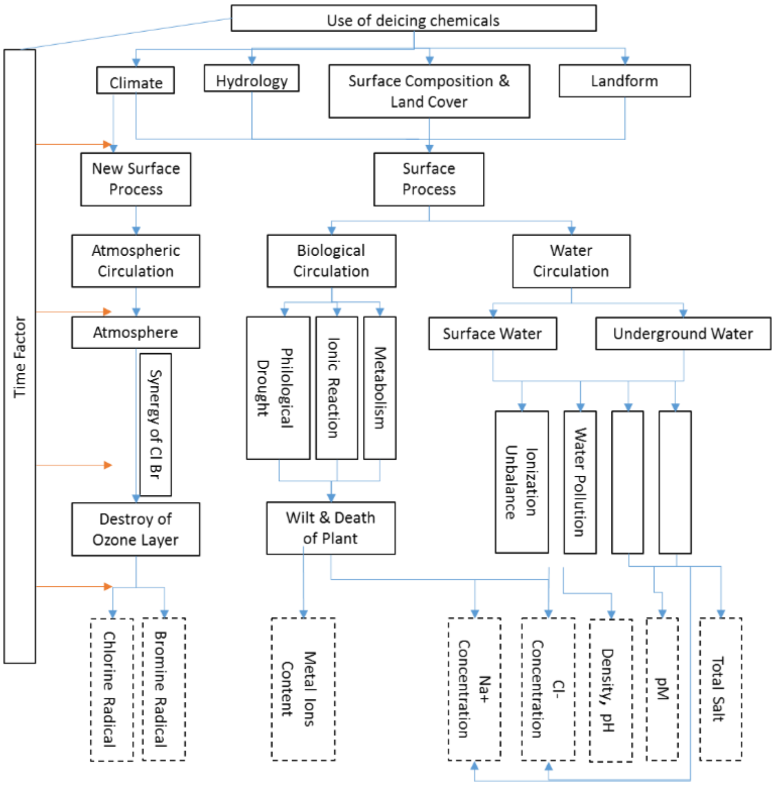

Figure 2.1. Pathways of Movement for De-icing Salt and Their Adverse Effects (reprinted from Dai et al. 2012, © ASCE)

Adding salt to roads and walkways has been a widely accepted practice in colder regions in the United States since the 1940s. Its use increased until 1972 when the Clean Water Act was enacted, at which time salt use plateaued, and then increased again after 1990. Salt usage has continued to increase over the last two decades (Figure 2.2). There is no indication of deicing salt usage decreasing in the near future. Increasing background levels are related to larger impervious surfaces and urbanization, road density, and human population density (Kelly et al. 2008). The amount of salt being used is further exacerbated by the adoption of the “bare pavement policy” for main roads in many communities. This means more salt is added to the roads before, during, and after precipitation to maintain a continuous clear roadway. By doing a trendline of the data from U.S. Geological Survey, the amount of salt being used is doubling every 21 years.

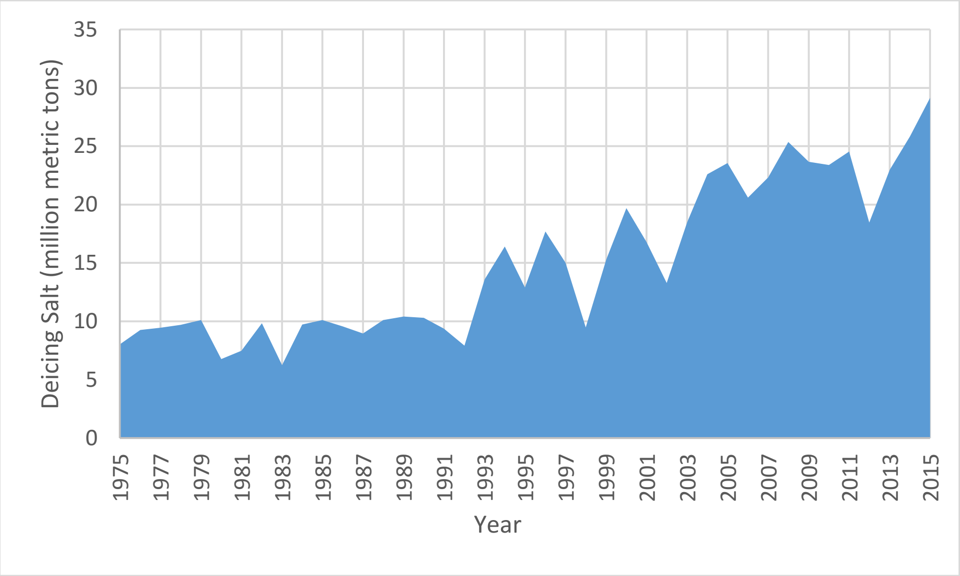

Figure 2.2. Deicing Salt Usage from 1975-2015 (U.S Geological Survey 2005; U.S. Geological Survey 2016)

Salinity is the saltiness, or the concentration of dissolved salt, in a body of water, including pore water of soils, and can be expressed in parts per million (ppm) or parts per thousand (ppt). Salinity can be measured a few ways; for this thesis, it was measured via conductivity. Conductivity is calculated as the ratio of the current density in the material to the electric field that causes the flow of current. For this research, it is assumed that all salts measured are sodium chloride or calcium chloride, as the other salts that are used in the deicing mixture are of negligible amounts. Villanova University uses mostly NaCl (90%) with the addition of $CaCl_2$ (9%) and Calcium Magnesium Acetate (1%). The amounts of each salt mixture depends on precipitation and temperature. Calcium chloride has a lowest eutectic point of all salt mixtures, at approximately -50°C, versus NaCl which is at -21°C (Table 2.2) (repreinted from Achkeeva et al. 2015, © ASCE). This means that $CaCl_2$ can produce water as a product of an exothermic reaction at much less lower temperatures than NaCl. Thus Villanova University will use more $CaCl_2$ at colder temperatures, changing the salt mixtures on the ice. Calcium chloride is not used in abundance because it is over three times more expensive.

Table 2.2. Deicing Salt Eutectic Points and Ice Melting Ability (from Achkeeva et al. 2015)

Salt	Ice Eutectic Point, °C	Salt Content in Eutectic, %	Ice Melting Ability, g/g at the temperature				
			-2	-5	-10	-15	-20
NaCl	-21.2	23.3	24.0	13.3	7.0	4.4	3.5
KCl	-10.6	19.7	15.7	9.1	4.4	0	0
$MgCl_2$	-33.6	20.6	26.8	11.5	7.3	5.7	4.8
$CaCl_2$	-49.8	30.5	21.7	9.9	6.1	4.6	3.9

2.2. Salinity in Surface Water (Creeks, Lakes, Rivers, Stormwater)

Surface waters are complex ecosystems and there are many pathways for salt ions to travel. These pathways (Figure 2.3) are (1) through soil to surface water or groundwater, with temporary or long-term storage in soils, (2) surface runoff with rain or snowmelt, (3) storm drains, (4) uptake by plants, and (5) airborne movement of dry dust of liquid droplets (Cunningham et al. 2008). This section focuses on surface runoff (2) with the next sections dealing with movement through soil (1) and plants (4) as well as chloride movement through groundwater. It takes a longer time for this ecosystem to adapt to changes that occur as many physical and biochemical cycles co-exist and interact (Meyer 1999). Thus treating and manipulating where stormwater flows is the first step in treating surface water.

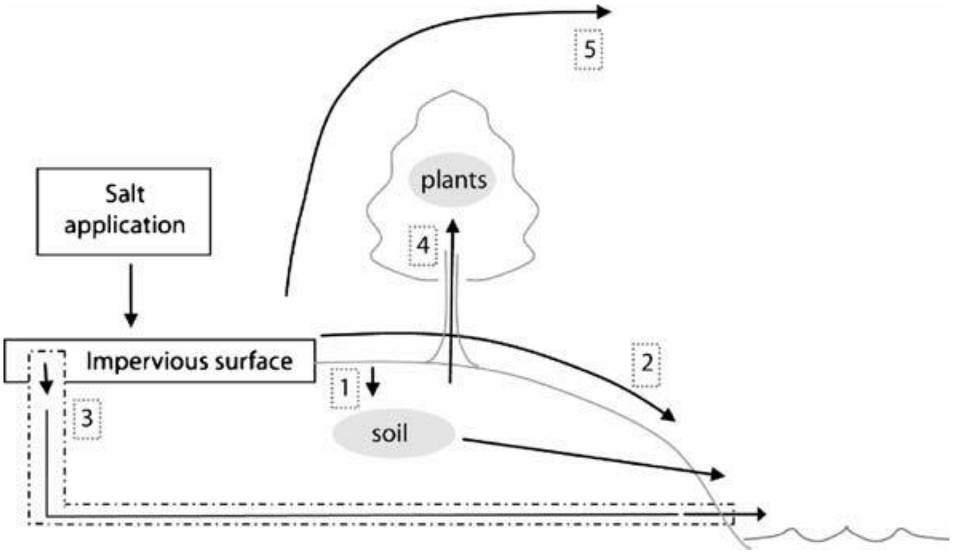

Figure 2.3. Surface Water Pathways (reprinted from Cunningham et al. 2008, © ASCE)

As rock salt is only effective in a certain temperature range (0-9°C) (Table 2.2), when applied at colder temperatures, the salt softens the ice and only melts about 10% of the total water content of the snow and ice layer (Ramakrishna and Viraraghavan 2005). To make up for its poor efficiency, salt is added in abundance. A study done in the Adirondack Mountains of New York monitored four different streams. These four streams had no source of chloride contamination other than their intersection with Highway/Route 28. The total amount of salt applied for this area was 39.9 metric tons and 37.2 metric tons over the two winters analyzed. The results showed that there was no significant difference in chloride levels downstream 50 meters or 100 meters (Ramakrishna and Viraraghavan 2005). This indicates that elevated chloride levels are not only an immediate problem because the chlorides continue to travel downstream. Another study was done in Black Creek and Don River for two different time periods. This research showed that the deicing salts in the water coincided with thaw periods, however, elevated levels of chlorides were observed during snow storms. Salts introduced during the winter months were stored in nearby soils and then slowly leached into the stream and caused elevated salt levels during the summer. Chloride levels in the winter months were high, and did persist at an elevated level through the spring and summer months (Ramakrishna and Viraraghavan 2005).

In a study done at Fall Creek near Ithaca, New York, a mathematical model showed that the lag between incoming chloride concentration and stream chloride concentration indicates that there is some process attenuating chloride. With a best-fit line to the observed stream chloride concentrations, the average residence time of a chloride ion was 50 years. This means that the concentration of chloride ions in the water will continue to gradually increase for the next 100-150 years, assuming that the use of chloride for de-icing continues to increase. By varying the model's five parameters (year when road salting began, the background stream chloride concentration, the concentration of the recharge water, the increase in road salt application rate constant, and the average residence time of chloride in the watershed), chloride ion concentrations will continue to rise for several decades assuming road salting continues at its present levels (Shaw et al. 2012). If the data continue this trend for the next century, it suggests that many rural streams in the Northeast that have low salt concentrations now could have baseline salt concentrations over 250 mg/L in the future. 250 mg/L is generally the cutoff for potable water and the level at which chronic toxicity occurs for many freshwater species (Jackson and Jobbagy 2005). While this outlook is discouraging, there are many salt management practices that are springing up to reduce the amount of salt being used. This includes PennDOT holding Snow Academy workshops to reduce the use of salt. The Snow

Academy informs townships of improved practices, as well as updates about equipment and technology (Wilt 2010). This not only reducing the cost of labor, but reduces the amount of salt needed.

Previously it was assumed that the salt concentration in rural streams would return to baseline levels in the summer when no salt was being applied, however, recent research indicates that that is not the case (Kincaid and Findlay 2009). One cause of the sustained elevated concentrations is that salts are building up over many years and are accumulating in the soil and shallow groundwater (Cantafio and Ryan 2014; Cooper et al. 2014; Kincaid and Findlay 2009). Thus, when the groundwater enters a stream as baseflow, the concentration of salt in the stream increases.

2.3. Salinity in Soil

There are many ways for salt ions to enter surface and groundwater. The most direct path is from impervious surfaces discharging to streams by storm drains or sheet flow. Where infiltration-based stormwater control measures (SCMs) have been implemented, the runoff moves into infiltration structures, like swales, stormwater basins, bioretention cells, or rain gardens. The salt ions then infiltrate into soil and flow into the shallow groundwater or discharge to surface waters (Casey et al. 2012).

SCMs are an emerging design philosophy that emphasizes maintaining predevelopment hydrology in areas that development has changed. This is primarily done through infiltration by treating runoff pollutants through contact with the media in the SCM (Kakuturu and Clark 2015).

SCM efficiency depends on the performance of the stormwater filtration media, regardless of whether this media is comprised of native soils or engineered media. Most often SCMs are located close to the pollutant-generating source as this can reduce the cost of transporting water to the treatment locations. These sources can include parking lots, highways, or buildings with high impervious areas

The SCM that is the focus of this research is a rain garden. Rain gardens intercept flow that would normally go into inlets and drainage pipes without a chance to infiltrate the stormwater runoff. Rain gardens can be designed to capture different amounts of precipitation. By capturing and infiltrating rainfall, rain gardens decrease stream bank erosion, downstream stormwater volumes, and non-point source pollution (Dietz and Clausen 2005; Heasom et al. 2006).

Salt, either as NaCl, $CaCl_2$, or $MgCl_2$, completely dissociates into its separate ions once mixed with water from snow or ice melt or precipitation. These ions react and accumulate differently in soil. Depending on the soil type/texture, clay content, and types of clay minerals present, the ions will have different degrees of influence. Magnesium and other multivalent cations are more reactive than Na^+ in soils, and thus are less toxic, but cause displacement and mobilization of metal ions, including heavy metals (Cunningham et al. 2008).

As both soil particles and chloride ions are negatively charged, the chloride ions easily move through the soil column. This makes the chloride anion highly conservative and most of the chloride applied will pass through the soil. In contrast, sodium ions are positively charged and negatively charged soil particles adsorb these ions by cation exchange sites. When a high concentration of sodium is present, the naturally occurring multivalent cations, as well as organic and inorganic particles in the pores of the soil, will become displaced. This leads to decreased soil permeability, decreased aeration, and overall increased overland flow, surface runoff, and erosion (Ramakrishna and Viraraghavan 2005).

Soil permeability is important to salt movement through the soil. A less permeable soil favors runoff and thus a greater horizontal salt movement on top of the soil. Another consideration is higher horizontal movement occurs in the winter due to ice and frost (Ramakrishna and Viraraghavan 2005). With a highly horizontal salt movement, a rain garden will not infiltrate or filter the water and the runoff will go directly into the sewer lines or receiving water body. Furthermore, salt-laden snow is often plowed into rain gardens. During melting, the salts permeate the filtration media, potentially changing the characteristics of the media and reducing infiltration rates (Kakuturu and Clark 2015).

When salt begins to infiltrate into the soil, it has an impact on the soil media, the soil ion exchange, and the root zone, which consequently affects the planted vegetation. A study done in southeast Sweden investigated whether the use of deicing salt would increase salinity and induce ion exchange causing acidification and increased metal concentration in outflowing waters. The study concluded that the use of deicing salt has a strong effect on soil and stream water chemistry. The applied salt caused an increase of salinity that was directly proportional to the accumulated amount of salt and did induce an ion exchange in the soil between Na^+ and Ca^{2+} and Mg^{2+}. This ion exchange also increased H^+ ions' mobility thus reducing alkalinity and increasing zinc and cadmium concentrations in streams (Löfgren 2001; Cunningham et al. 2008). Kakuturu and Clark (2015) analyzed the soil fabric through microscopic studies (thin slices) and found that through the ion-exchange process induced by salts, dispersion and/ or flocculation can occur thus eventually clogging the filter media.

Salt ions in soil also affect plant life and performance. Plants can tolerate salinity to a certain threshold. When the salinity exceeds that limit, plants' development, growth, and yield are adversely affected (Patel 2002). Sodium ions are not an essential ion for plants, but are for halophytes. Halophytes accumulate salt in vacuoles to maintain turgor and growth. Soils are classified into three different groups (saline soils, sodic soils, and saline sodic soils) based on their electrical conductivity, pH, and sodium exchange percentage. Nonsaline soils (normal) have 0.1-1% Na, with very little exchangeable Na^+. Sodic soils are rich in sodium, which can be toxic to most plants as it disperses soil colloids. Saline soils can go back to nonsaline soils through leaching with fresh water with no significant increase in soil pH (Mitra 2015b). The primary area of Na^+ toxicity is in the shoots. Na^+ accumulates and disrupts the metabolic process which can result in necrosis of leaf tips and edges (Mitra 2015b). While sodium ion toxicity has been widely studied, the toxicity of chloride ions as an independent ion has not (Mitra 2015a).

Chloride ions are an essential plant nutrient that is involved in osmotic processes such as regulation of water loss, transport of nutrients and photosynthesis, as well as the regulation function of several enzymes, thus reducing disease (Mitra 2015a). If there is a chloride deficiency, the leaves will show wilting, chlorosis (a disease marked by yellowing or blanching), necrosis, and/or an unusual bronze discoloration (Broyer et al. 1954). However, chloride can be toxic to plants in high concentrations; concentrations exceeding 4-7 mg/g of dry weight for chloride-sensitive species and 15-50 mg/g for chloride-tolerant plants can be toxic (Xu et al. 2000).

Chloride is soluble in water and leaches to lower depths in porous soils. It is not adsorbed by organic matter or clay and is not readily precipitated from solution. Chloride ions can increase from a high water table, impeded drainage, capillary rise from lower depths, or irrigated water with high chloride ion content (Mitra 2015a).

Overall these studies on soil, filter media, and root zone indicate that engineers need to be cautious about introducing significant amounts of salt into infiltration SCMs as the chlorides can be harmful to plants, infiltration capacities, and could reach the water table. Stormwater management and environmental engineers need to consider these complications in rain gardens in the design and implementation of their systems (Kakuturu and Clark 2015).

2.4. Salinity in Groundwater

Unlike groundwater which is characterized by a clearly defined volume, surface waters have an almost unlimited dilution capacity attributable to their flow rate and volumes. Seasonal variations of salt concentrations in groundwater are not clearly distinguished due to the time it takes for salt solutions to percolate from the surface through the soil. The most significant impact of road salting on groundwater is water supply contamination which can result in organoleptic characteristics (salty taste) of drinking water.

A study was performed in Massachusetts where researchers collected samples from wells installed various depths at 10 sites. Each well was down gradient of the highway with respect to the water table. In some of the locations, the concentration of the chloride had increased beyond the 250 mg/L recommended by the USEPA as an upper limit for drinking water. Similar results were found in roadside wells in Michigan, Wisconsin, Illinois, New Hampshire, Maine, Ohio, and Connecticut (EPA 1988; Ramakrishna and Viraraghavan 2005). Other studies in the northeastern US and Canada have shown similar results. For example, in the greater Toronto area, researchers surveyed 23 springs and found chloride concentrations topping 1200 mg/L arising from road salt use. This type of increase in salinity is a major concern for long-term potable water supply because once the groundwater becomes salty, it is expected to take decades to centuries for the salts to disappear, even if all road salting ceased (Williams et al. 2000; Jackson and Jobbagy 2005).

Groundwater contamination is a unique challenge in that it is difficult to predict the subsurface behavior of contaminants and to develop a course of remedial action and method that can resolve the problem. A step towards a solution is the monitoring and assessment of changes in groundwater quality (Williams et al. 2000). Monitoring itself can be challenging unless a long-term sampling program is in effect. This is because the data collected do not show immediate or short-term changes or trends. Implementing and collecting data can be expensive to monitor groundwater samples regularly, particularly if drilling is needed.

Chapter 3. Methods

3.1. Study Area

Villanova University retrofitted an existing traffic island to become a bio-infiltration rain garden. This rain garden intercepts flows to a single entry point (Figure 3.1) that would otherwise discharge to surface water through a traditional stormwater sewer system. Any storms larger than the designed 3.81 centimeters, storm volume will overflow into the existing storm sewer system and discharge directly to Darby Creek. (Heasom et al. 2006; Emerson and Traver 2008).

The rain garden is located in a grassy area in a parking lot on Villanova University's West Campus and has been operating since 2002. This parking lot serves a recreation area and a dormitory complex. The drainage area is roughly 5261 square meters total and is 44 percent impervious cover. The rain garden basin has a 1.22-meter layer of sand mixed with preexisting soil.

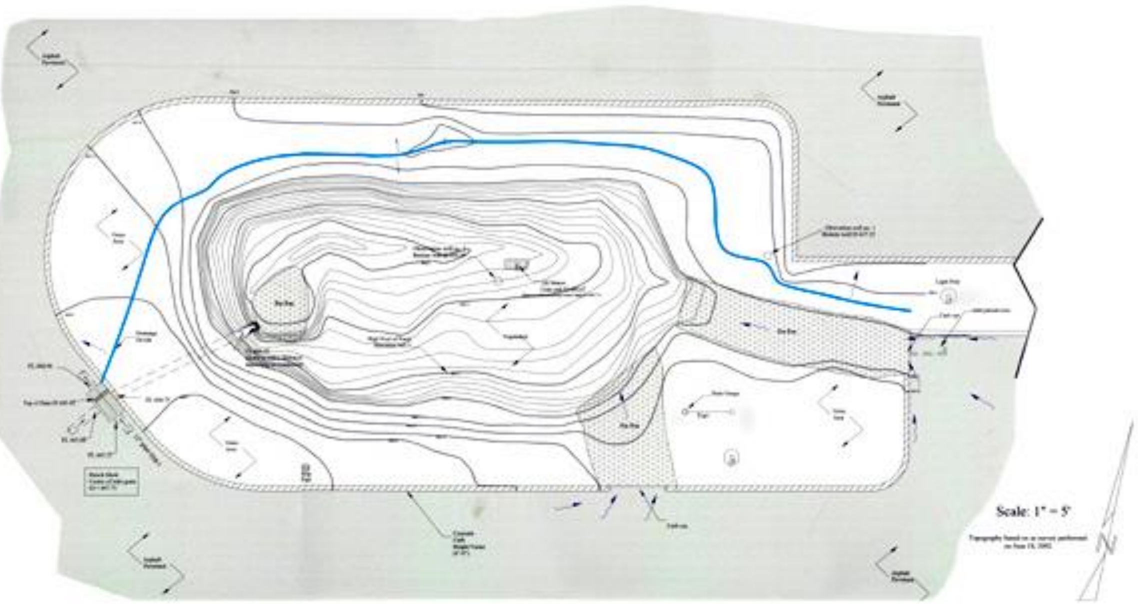

Figure 3.1. Contour drawing by William Heasom, PE (Villanova University 2005)

Below is the soil profile for the rain garden. Figure 3.2 shows the soil profile from A-A' while Figure 3.3 shows the soil profile from B-B'. These profile lines are shown in Figure 3.7 along with the locations of the groundwater wells. The rain garden contains USDA classification soil types of Sandy Loam and Loamy Sand. Beneath the rain garden, the soil goes from Sandy Loam to Loamy Sand to Loam and finally into bedrock at approximately 5.5 meters below.

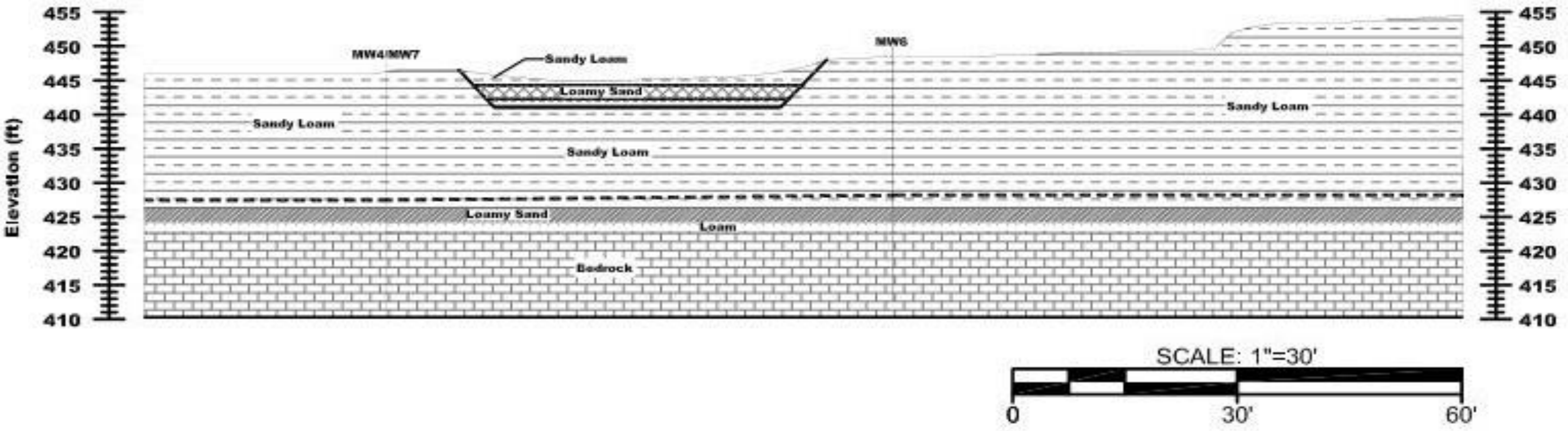

Figure 3.2. Soil Profile from A-A' with USDA Classification (reprinted from Nemirovsky et al. 2015, © ASCE)

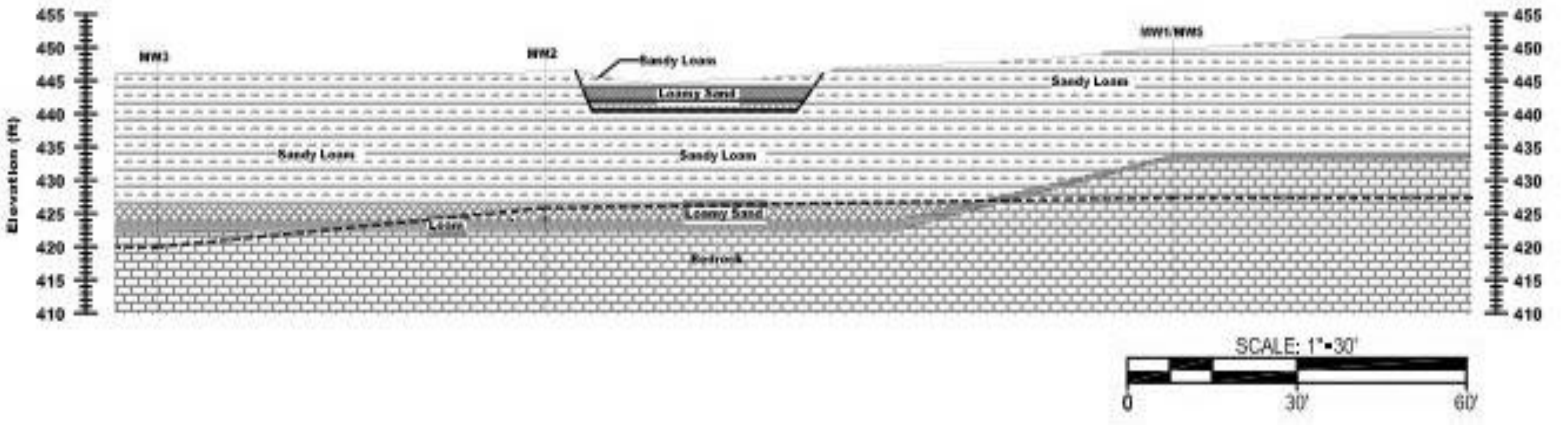

Figure 3.3. Soil Profile from B-B' with USDA Classification (reprinted from Nemirovsky et al. 2015, © ASCE)

The original vegetation planted (Table 3.1) was selected to handle both dry and wet conditions and elevated salt levels. In 2010, a plant survey was done to determine whether the plants originally planted are surviving or not (Figure 3.2). There were a few plants that had become extinct since the rain garden was planted. These include American Beach Grass, Coastal Panicgrass, and Marsh Elder. While a few species have not survived in the rain garden, there are many invasive species that are persevering. A few of these include Mugwort, Box Elder, and Sycamore. Overall, the plants that seem to be surviving in the rain garden are at least moderately tolerant of salts. Plants that are less so, like the American Beach Grass and Marsh Elder, seem to become extinct.

Table 3.1. Plant Species Originally Planted in the Rain Garden

Plant Species	**Common Name**
Grasses	
Ammophila breviligulata	American Beach Grass
Panicum amarum	Coastal Panicgrass
Panicum vigatum	Switch Grass
Schizachyrium scoparium	Little Bluestem
Herbs	
Solidago sempervirens	Seaside Goldenrod
Woody Plants	
Photinia melanocarpa	Black Chokeberry
Baccharis halimifolia	Groundsel Tree
Ilex verticillata	Winterberry
Iva fretescens	Marsh Elder
Prenus maritima	Beach Plum

Table 3.2. Plant Species in Rain Garden in 2010 (Greising 2011)

Plant	Vegetation Status	Salt Tolerance
Grasses		
American Beach Grass	Extinct	Slightly
Coastal Panicgrass	Extinct	Slightly
Switchgrass	Surviving	Moderate
Little Bluestem	Surviving	Moderate
Mugwort	Invasive	Moderate
Aster	Invasive	Moderate
Boxelder	Invasive	Moderate
Smartweed	Invasive	Low
Green Foxtail	Invasive	Moderate
White Snakeroot	Invasive	Moderate
Herbs		
Seaside Goldenrod	Surviving	Moderate
Woody Plants		
Black Chokeberry	Surviving	Moderate
Groundsel Tree	Surviving	Moderate
Winterberry	Surviving	Low
Marsh Elder	Extinct	Low
Beach Plum	Surviving	Moderate
Sycamore	Invasive	Moderate

3.2. Instrumentation

This site has been extensively instrumented. Precipitation is measured using an American Sigma Tipping Bucket Rain Gauge Model 2149 (Figure 3.4). The tipping bucket is a 20.3 centimeter diameter ‘bucket’ that funnels rain to the tipping mechanism where it tips alternatively side to side producing a contact closure to record amount. It accurately measures rainfall to 0.254 millimeters. The rain gauge is intermittently checked for debris and obstructions and calibration is checked after storms by comparing the volumetric (old-fashion) rain gauge located on the site as well.

Figure 3.4. American Sigma Tipping Bucket Rain Gauge Model 2149

To measure soil conditions, Decagon soil sensors (Figure 3.5) were installed in April 2012 at 23 and 91 centimeters and then were removed to be replaced with Steven’s HydraProbes (Figure 3.5) in September 2013 at varying depths of 10, 35, 65, and 91 centimeters. For both Decagon and Steven’s, the readings are taken every five minutes and include air and soil temperature and soil conductivity. Accuracy specifications are shown for Decagon soil sensors and Steven’s HydraProbes in Table 3.3.

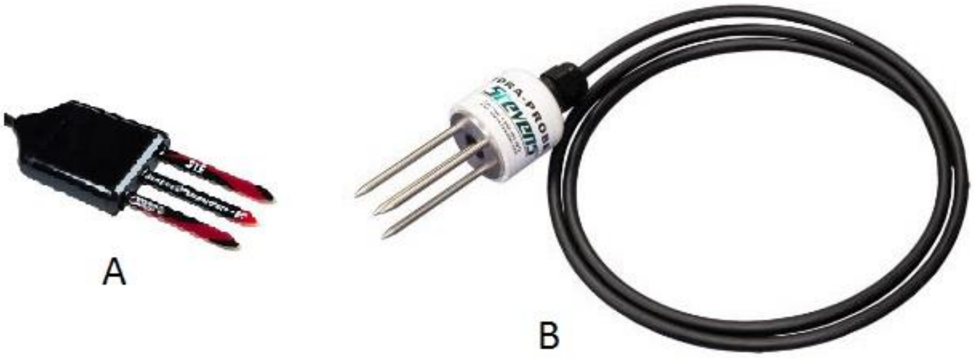

Figure 3.5. A) Decagon Soil Sensor   B) Steven's HydraProbe

Table 3.3. Decagon Soil Sensor and Steven's HydraProbe Accuracy Specifications

	Decagon Soil Sensor	Steven's HydraProbe
Real Dielectric Permittivity	+/- 1 from 1-40	+/- ≤ 1.5% or 0.2
Bulk Electrical Conductivity	+/- 10% from 0-7 dS/m	+/- 2.0% or 0.02 S/m (whichever is greater)
Temperature	+/- 1° C	+/- 0.3° C

There are eight groundwater wells that have been installed to monitor the effects of mounding around the rain garden. Each of these have been installed at varying dates and depths, shown in Table 3.4. Each of the wells are equipped with In-Situ Inc. Aqua Troll 200 Multi-meters with the setup shown in Figure 3.6. The AquaTrolls are self-contained data loggers that record the depth to water, temperature, conductivity, and specific conductivity (and use equations to calculate other variables including salinity and total dissolved solids). These instruments record every 15 minutes and locations are shown in Figure 3.7.

Table 3.4. Information on Groundwater Monitoring Wells

Well #	Date Installed	Installation Type	Depth Below the Surface
MW-1	June 2007	Air Rotary Drill Rig	11.2 meters
MW-2			9.2 meters
MW-3			9.2 meters
MW-4	Inactive (Currently not in use)		
MW-5	March 2012	Air Rotary Drill Rig	12.0 meters
MW-6			
MW-7			
MW-8			

Figure 3.6. Groundwater Well Setup with Aquatroll, Desiccant, and Computer (image courtesy of Villanova University: Villanova Urban Stormwater Partnership)

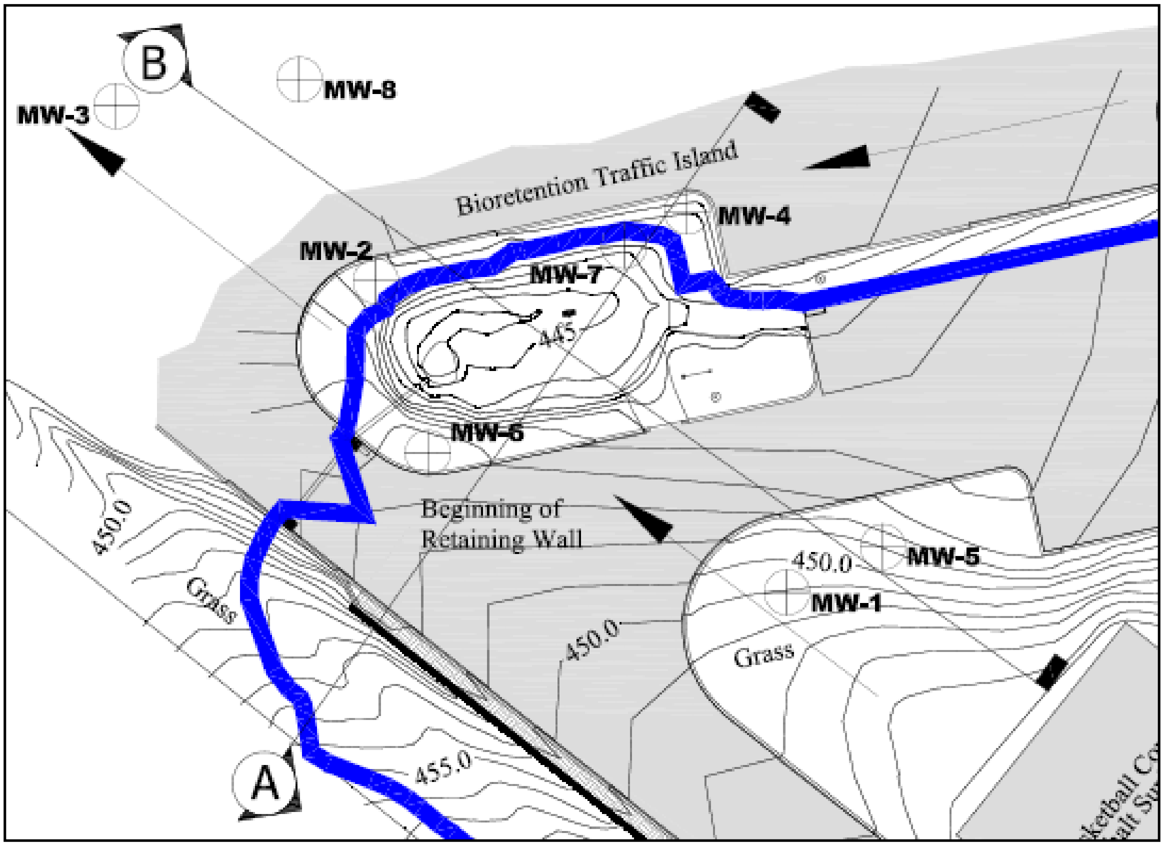

Figure 3.7. Locations of the Eight Groundwater Monitoring Wells (reprinted from Machusick et al. 2011, © ASCE)

3.3. Water Quality Sampling

Surface water conductivity/salinity is determined from the first flush sampler. The first flush sampler is used to capture the early runoff from storm events. It is a precast housing in the retrofit concrete of the inflow channel. A plastic container is placed prior to a storm event for sampling. A sample is then collected following the storm event and tested in the laboratory. This testing includes total suspended solids (TSS), total dissolved solids (TDS), chloride ions, and conductivity. This research used conductivity methods EPA Method 120.1: Conductance

(Specific Conductance, µmhos at 25°C) by Conductivity Meter and Standard Methods: 2510B: Conductivity – Laboratory Method.

3.4. Geographic Information System (GIS)

ArcGIS was used to calculate the amount of salt distributed in the drainage area. This was done by using data procured from Villanova University’s Facility Management Office, including the amount salt bought for the year and their estimated applied area. By using GIS mapping tool, the drainage area was determined and traced, then pervious and impervious area calculated shown in Figure 3.8. The red is the impervious area and the green is the pervious area with the total area outlined in black.

Figure 3.8. Drainage Area into the Rain Garden

Villanova University’s Facilities Management Office estimates that 20% of the salt applied on Villanova’s campus is used on West Campus. Using this estimate, and the percent of impervious area on West Campus, along with the amount of impervious area in the rain garden drainage area, the amount of salt entering the rain garden each year was determined.

3.5. Conductivity to Salinity Procedure

Conductivity is one of the indirect methods that can quantify the amount of dissolved salts in a given mass of solution. Normally the only way to measure true, or absolute, salinity is to do a complete chemical analysis. A complete chemical analysis is laborious, thus indirect methods, such as conductivity, sound speed, density, or refractive index, are often used. Table 3.5 provides the precision of measurement and salinity of conductivity and other indirect methods like density and sound speed. Conductivity has the best precision, but it only responds to ionic solutes; density responds to all dissolved solutes with less precision. Since this study focuses on ionic chloride ions, conductivity is an acceptable means of estimating salinity (American Public Health Association 1999).

Table 3.5. Precision of Conductivity Compared to Other Indirect Methods (from American Public Health Association 1999)

Property	**Precision of Measurement**	**Precision of Salinity**
Conductivity	+/- 0.0002	+/- 0.0002
Density	+/- 3 x 10^{-6} g/cm^3	+/- 0.004
Sound Speed	+/- 0.02 m/s	+/- 0.01

Soil and groundwater readings are recorded in electric conductivity units of microSiemens per centimeter (µS/cm) and need to be converted to practical salinity units (PSU) and standardized with temperature. This conversion uses multiple equations that allow for a temperature correction (to 15° C) to standardize the data. Equation 1 shows the general equation to calculate salinity in seawater, S. S is the practical salinity scale in PSU followed by Equation 2, Equation 3 and Equation 4 as supplementary equations to standardize temperature. If the measurements are taken from estuarine water, a second calibration must be made (Equation 5) (American Public Health Association 1999). An estuarine environment is defined as an environment that has brackish water, which is water that is saltier than fresh water but not as salty as seawater. This is acceptable as the water coming in is saltier than freshwater.

Equation 1.

$$S = a_0 + a_1 R_t^{1/2} + a_2 R_t + a_3 R_t^{3/2} + a_4 R_t^2 + a_5 R_t^{5/2} + \Delta S$$

Where ΔS is given as:

Equation 2.

$$\Delta S = \left[\frac{t - 15}{1 + 0.0162(t - 15)}\right]\left(b_0 + b_1 R_t^{1/2} + b_2 R_t + b_3 R_t^{3/2} + b_4 R_t^2 + b_5 R_t^{5/2}\right)$$

And, where a_0 to a_5 and b_0 and b_5 are all constants:

$a_0 = 0.0080$ $b_0 = 0.0005$
$a_1 = -0.1692$ $b_1 = -0.0056$
$a_2 = 25.3851$ $b_2 = -0.0066$
$a_3 = 14.0941$ $b_3 = -0.0375$
$a_4 = -7.0261$ $b_4 = 0.0636$
$a_5 = 2.7081$ $b_5 = -0.0144$

valid from S = 0 to 40, where:

Equation 3.

$$R_t = \frac{C \text{ (sample at } t\text{)}}{C \text{ (KCl solution at } t\text{)}}$$

R_f: Conductivity ratio
t: temperature of solution in degrees Celsius (C)
C (Sample at t) (µS/cm): conductivity of sample at specific temperature t
C (KCl solution at t) (µS/cm): is a measure of the conductivity of KCl solution containing a mass of 32.4356 g KCl in a mass of 1 kg of solution, the solution has a Salinity of 35 PSU at 15°C. It can be measured using Equation 4.

Equation 4.

$$\mathrm{C}\ (\mathrm{KCl\ solution\ at}\ t)\ (\mu S/cm) = -0.0267243\, t^3 + 4.46636947 t^2 + 861.3027640\, t + 29035.1640851$$

Equation 5.

$$S = S_{PSS} - \frac{a_0}{1 + 1.5X + X^2} - \frac{b_0 * f(t)}{1 + Y^{1/2} + Y^{3/2}}$$

S_{PSS}: value determined from the Practical Salinity Scale given earlier,
a_0 = 0.008
b_0 = 0.0005
X = 400*R_t
Y = 100* R_t
f(t) = (t-15)/[1+0.0162(t-1)]

For, the conductivity readings of surface water measurements were obtained in the laboratory using a Hach HQ40d Conductivity meter in conjunction with a CDC401 Conductivity probe and recorded in units of µS/cm. Calibrations occurred before each use, using a 1,000 mg/L standard of NaCl. Temperature and pH were also recorded with the same instrument at the same time. Since these measurements were obtained in the laboratory, it was assumed that the temperature was close to t=15°C and no standardization needs to occur.

Chapter 4. Data and Results

4.1. Collected Data

Surface water data was analyzed from storm events in 2012-2015. Storm events are defined as storms larger than 0.64 centimeters. This is standard from the Villanova Urban Stormwater Partnership Bioinfiltration Traffic Island procedure as not all storm events under 0.51 centimeters produce runoff/ ponding. However, the majority do (87%). The surface water conductivity is taken from samples SA01 and SA02. These samples are taken in µS/cm and then converted to practical salinity units. These samples are surface water (ponding water) grab samples taken after approximately 0.25 centimeters ponding and at the end of the storm event (Figure 4.1).

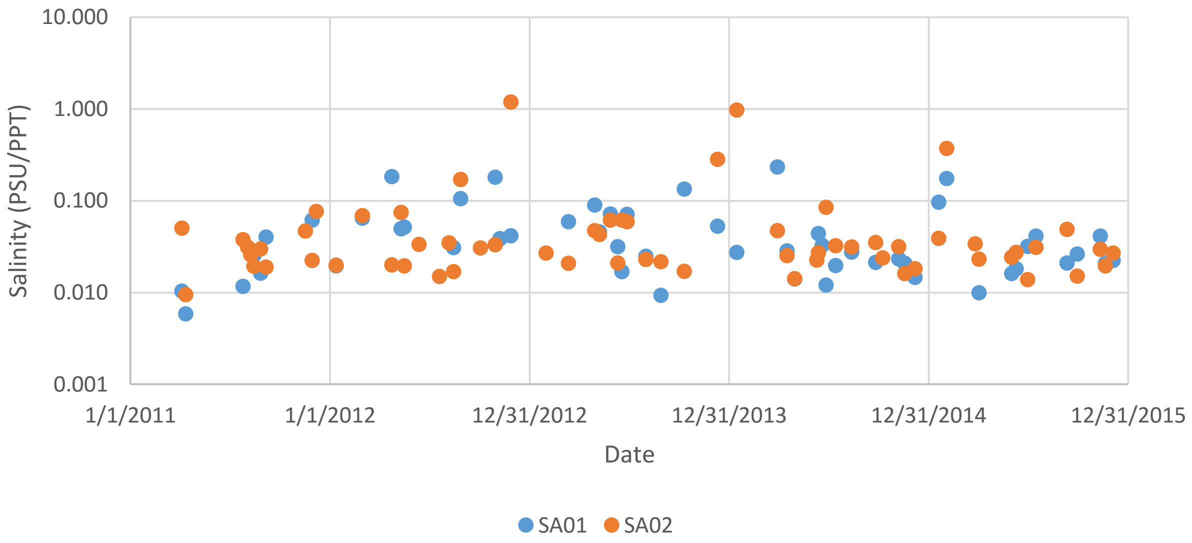

Figure 4.1. Surface Water Salinity of Grab Samples SA01 and SA02

The majority of salinity values from SA01 and SA02 are within the same order of magnitude allowing the samples to be averaged. The averages are used for the data analysis and comparison.

Soil and groundwater data are continuously recorded in 15 minute increments. Daily averages were calculated from these values. Soil and groundwater conductivity are recorded in µS/cm or S/m and converted to practical salinity units. Soil conductivity readings between April 2012 and July 2013 are taken at 23 and 91 centimeters (9 and 36 inches), between September 2013 and December 2015 the readings were taken at 10, 35, 65, and 91 cm. The soil probes have gaps of missing data as between August 2013 and November 2013, the Decagon probes were replaced by Steven's probes causing programming difficulties. Like the surface water data, the soil data and groundwater data were averaged together. Wells 1, 5, 6, and 7 are used, not because they are similar in value, but because these are the wells that are in the drainage area of the rain garden. As shown previously, Wells 1 and 5 are upstream of the rain garden and wells 6 and 7 are downstream, but are still contained in the rain garden's drainage area. Soil probe depths of 23 cm and 91 cm, as well as 10 cm, 35 cm, 65 cm, and 91 cm, are almost identical which is seen in Figure 4.2. Groundwater wells, MW1-5-6-7-8, were averaged together as an average provided the most useful information. These wells were selected as they are located within the rain garden drainage area. The different groundwater wells' salinity is shown in Figure 4.3.

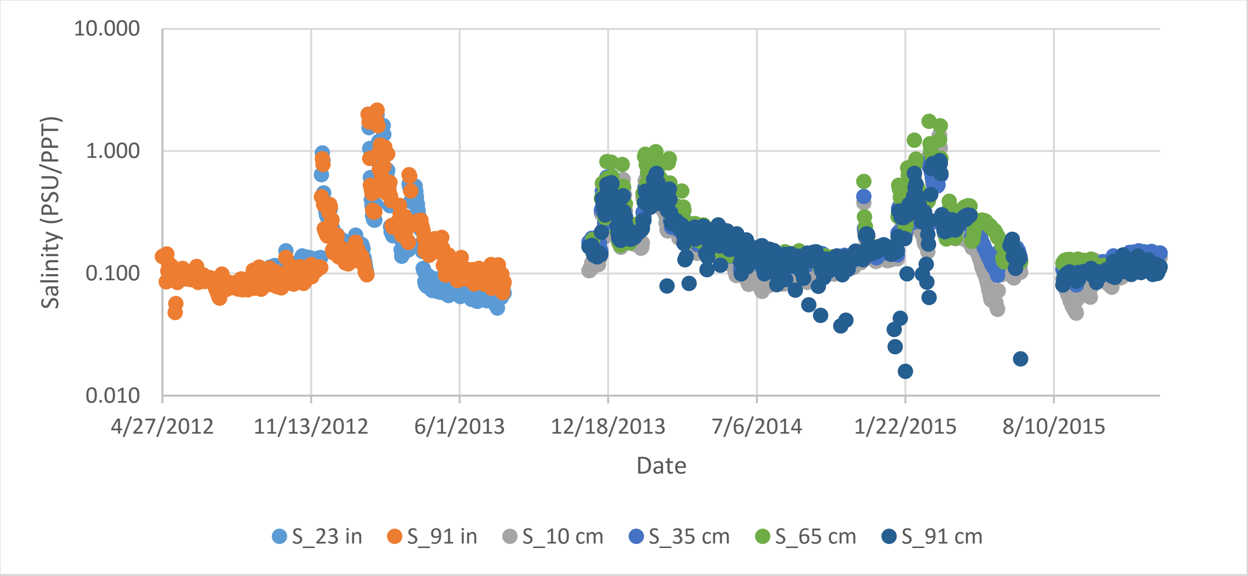

Figure 4.2. Rain Garden Soil Salinity for Depths of 23 and 91 Centimeters (4/2012-7/2013) and 10, 35, 65, and 91 Centimeters (9/2013-12/2015)

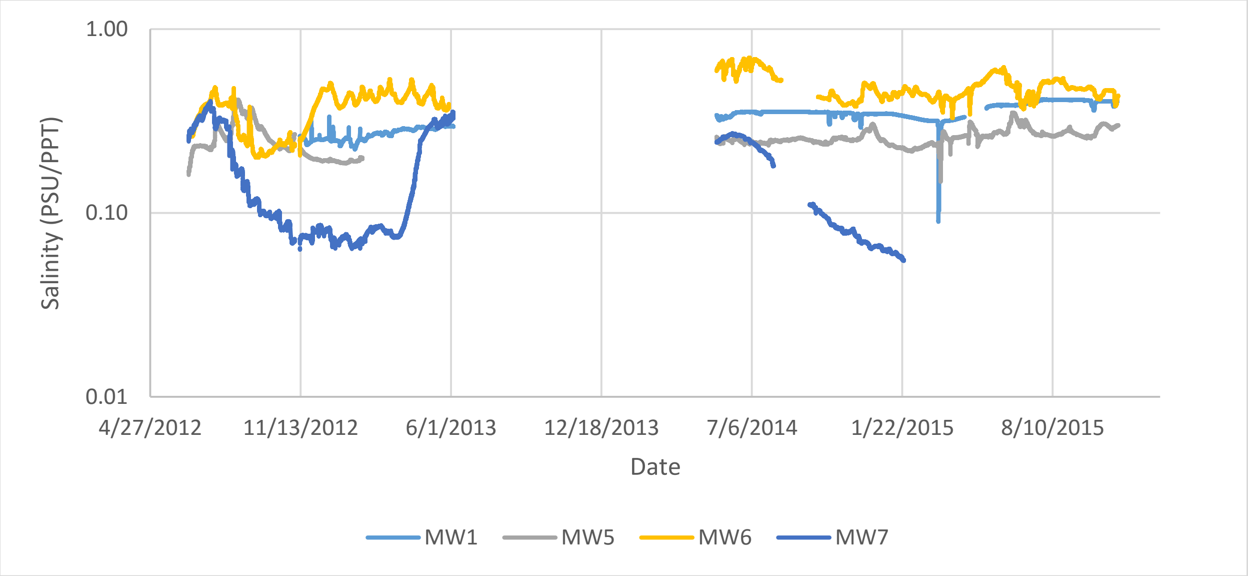

Figure 4.3.Groundwater Salinity for Monitoring Wells 1, 5, 6, and 7

All of the soil moisture sensors on Villanova's campus are located beneath infiltration SCMs. However, a comparison site was desired to place the salinity values measured under the rain garden into context. Fortunately, soil moisture sensors were installed in soils located next to a park in Narberth, PA, which is approximately 8.1 kilometers away. The soil type in Narberth is the same as the natural, background soil at Villanova University and may be used as a control to the values collected under the rain garden. The similarity of the soils was verified by comparing the USGS Soil Survey and grain size distributions. Both Villanova University's and Narberth's native soils are USDA classified as a silt loam (CdB at Villanova University and UrmB at Narberth Park) by USGS (Appendix: Figure 0.1 and Figure 0.2). The grain size distributions are shown in Figure 4.4. According to the United States Department of Agriculture (USDA) system both the Narberth and Villanova University soils are a Sandy Loam; according to the Unified Soil Classification System, both soils are a Silty Sand (SM).

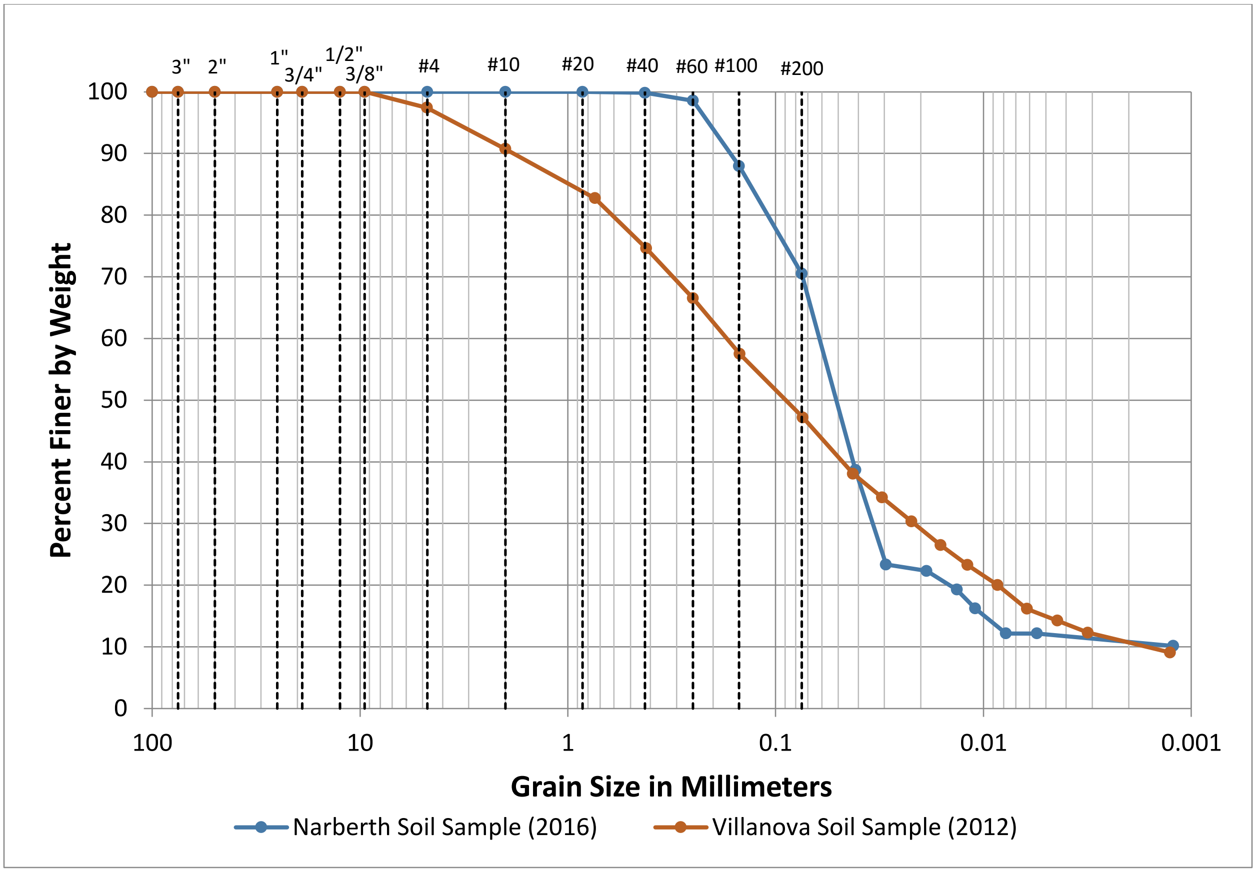

Figure 4.4. Grain Size Distributions of Narberth Soil and Villanova University Soil Samples

The soil moisture probes in Narberth are buried adjacent to the sidewalk. Salt that would be drained or deposited on the area where the probes are located should be minimal; only salt that was applied to the sidewalk would be expected. The soil probes are buried at the same depths as the probes in the rain garden on campus. Their daily averages are shown in Figure 4.5 from November 21, 2014 to December 26, 2015. As they are very similar values, their average was taken to provide a baseline analysis for the rain garden comparison.

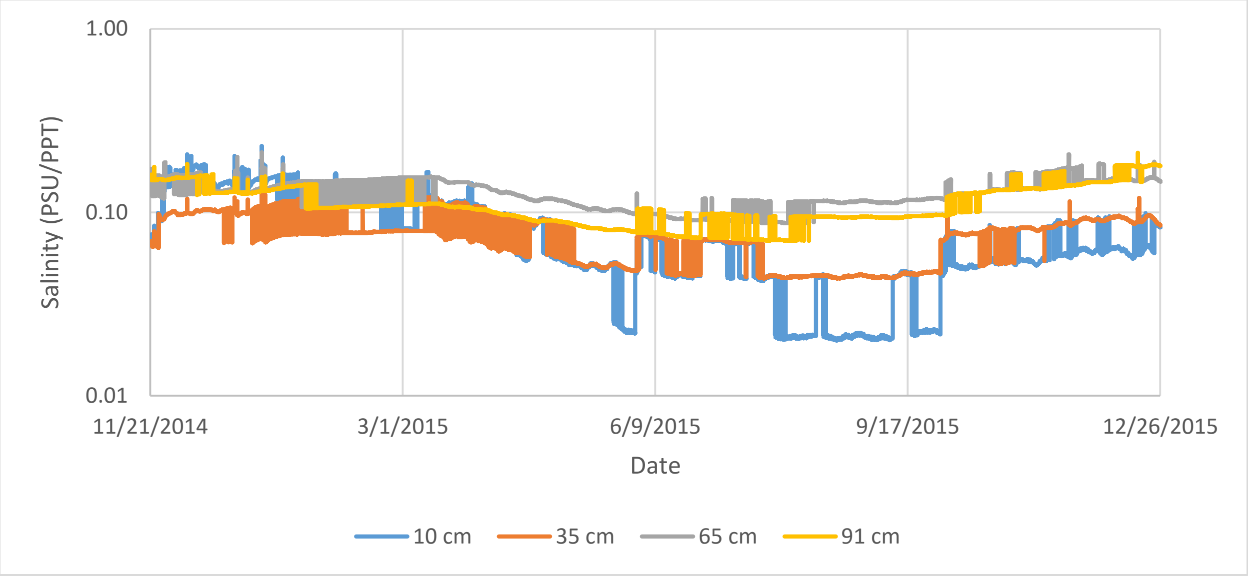

Figure 4.5. Narberth Park Soil Salinity for Depths of 10, 35, 65, and 91 Centimeters

To calculate the amount of salt entering the rain garden, geographic information system or ArcGIS (GIS) software was used. Data were collected from the GIS software, depicting West campus area and the area going into the rain garden. For years 2013-2015, the amount of salt bought for the entire Villanova campus is known. It is assumed that all the salt bought was used. Knowing that west campus is 20% of the area of Villanova campus, the amount of salt flowing into the rain garden can be estimated (Table 4.1). The amount of salt used for years 2013-2015 are 19.0, 35.2, 15.8 metric tons, respectively.

Table 4.1. Amount of Salt Added to Campus and the Rain Garden for 2013-2015

	Area (m^2)	Percent of Total	Kilograms (2013)	Kilograms (2014)	Kilograms (2015)
Amount of Salt, Total			243791	452118	202346
West Campus, Total	136398	100	48758	90424	40469
West Campus, Pervious	60287	44.2	-	-	-
West Campus, Impervious	76111	55.8	48758	90424	40469
Raingarden Drainage, Total	5296	3.9	19016	35265	15783
Metric Tons			19.0	35.3	15.8

4.2. Data Analysis

After sorting and processing the surface water samples, soil probes, and groundwater data, these data were combined with daily precipitation over the time period. Surface water, soil probes, groundwater, and Narberth soil data is presented in Figure 4.6. Gaps appearing in the Villanova rain garden soil data and groundwater data are from malfunctions in the instrumentation.

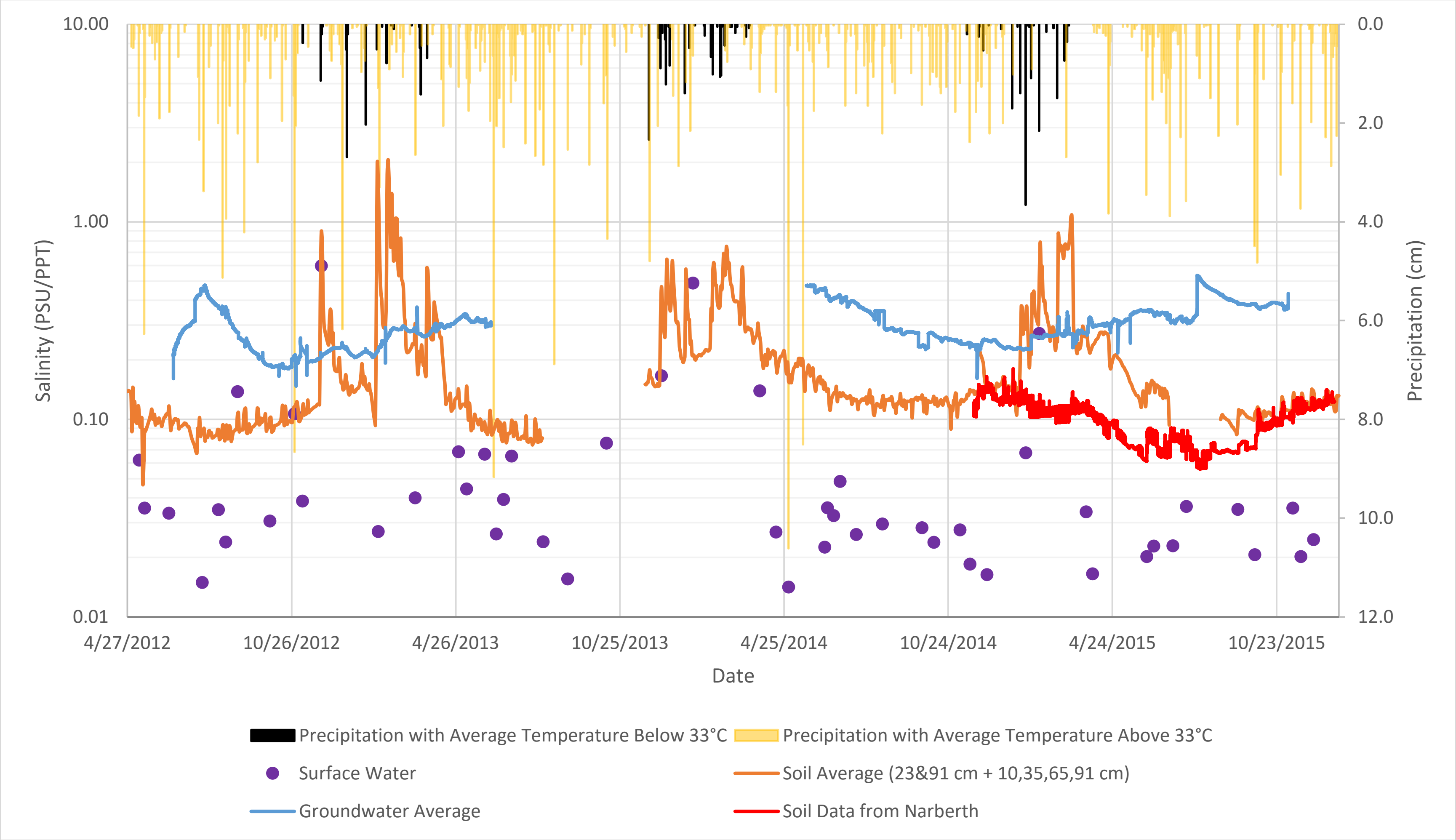

Figure 4.6. Salinity Data for Surface Water, Soil (From Rain Garden and Narberth Park), and Groundwater Shown with Precipitation Amounts between 4/27/2012 and 12/31/2015

Figure 4.6 displays the salinity of the surface water is the lowest, increasing as it goes through soil, with groundwater salinity being the highest. Peaks in surface water and soil salinity correspond to the same time of year each year, between December and March. This makes sense as deicing salt is only applied in the colder months due to snow and ice.

Spikes in surface water correspond to spikes in soil salinity. While there are more spikes in the soil, there are not as many in the surface water, this is an artifact of the fact that the storms less than 0.64 centimeters are not tested for water quality parameters. Also, high precipitation does not necessarily mean spikes in surface water or soil salinity as the changes in concentration are dependent upon the antecedent and current weather conditions. The previous days or weeks needed to be cold enough to require salt application on the impervious surfaces and then the temperature needed to rise high enough to melt the snow or ice or allow for rain to rinse the salt into the rain garden. This can be seen by the different precipitation colors. As temperature and precipitation is a daily average and can fluctuate during the day, a divider of 2°C (35.6°F) is taken, so that any precipitation that falls on days less than 2^{o}C is assumed to be snow or freezing rain and deicing salt is applied. This is shown by the black bars. Any precipitation on days with a temperature average of 2^{o}C is shown by yellow bars.

The groundwater salinity varies seasonally. The seasonal increase occurs after the winter months, after the spikes in surface water and soil salinity. The lag time between the spike in soil salinity and groundwater salinity is approximately 4-5 months.

By zooming in on one year of data, 12/1/2014 and 11/30/2015, monthly trends can more closely examined. This examination reveals that the Narberth soil salinity follows the baseline of the soil salinity from the rain garden (shown in Figure 4.7). The peak of the soil salinity from the rain garden starts mid-January and does not go back to normal levels until July. This means over seven months of the year the salinity levels can range from 2-10 times their normal levels.

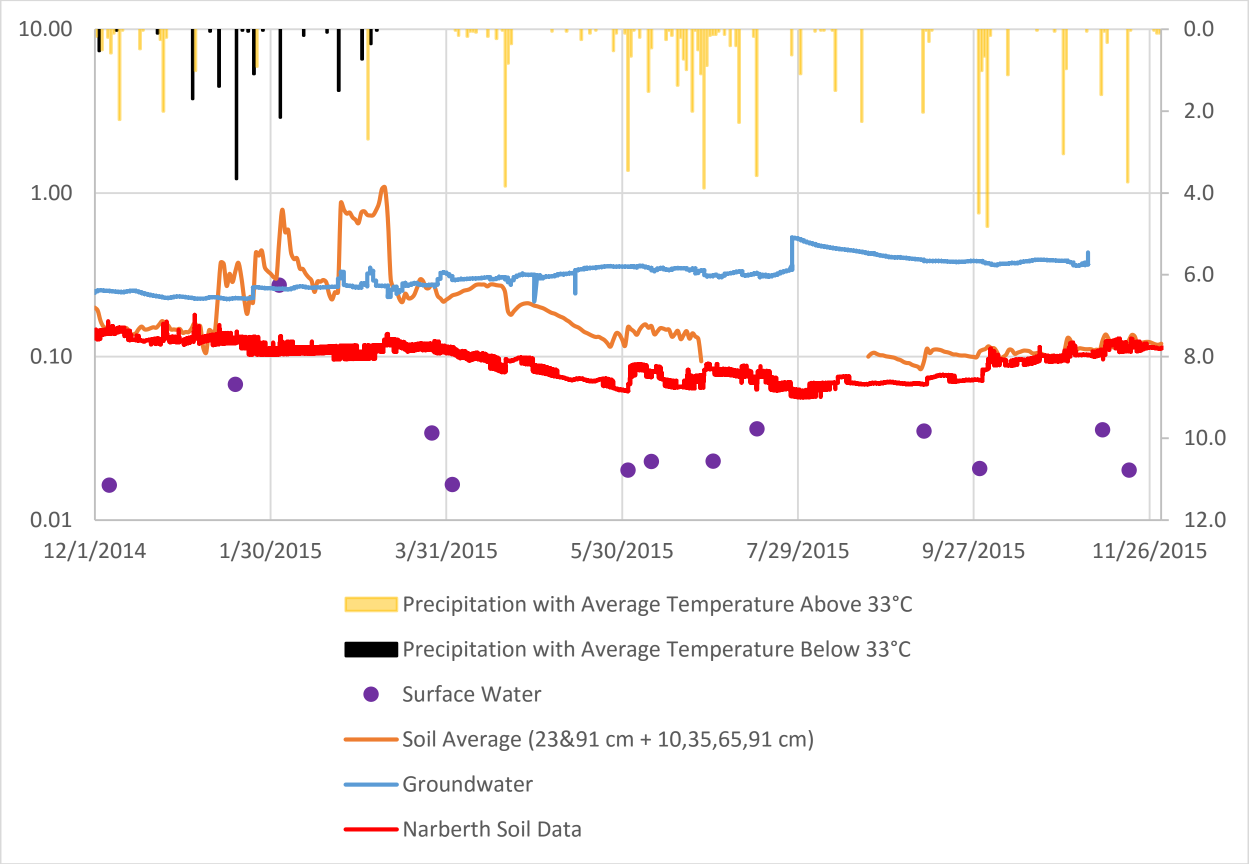

Figure 4.7. Salinity Data for Surface Water, Soil (From Rain Garden and Narberth Park), and Groundwater Shown with Precipitation Amounts between 12/1/2014 and 11/30/2015

4.3. A Comparison of Chloride Transport in Constructed Stormwater Wetland

In a long-term study of the Schuylkill River indicated that the chloride and sodium ion concentration increased over time and became elevated during the winter months from road salt application. This is significant as the Schuylkill River is the downstream receiving water of the constructed stormwater wetlands (Interlandi and Crockett 2003).

The presumption is that the applied salts flush through the stormwater control measure and leave little to no effect on the areas, whether it is the traffic island or the constructed stormwater wetlands. Similarly, to the rain garden, recent research has presented evidence that up to 77% of chloride may be retained in the watershed (Novotny et al. 2009) and may be elevated for longer time frames than previously thought. A study in Sweden reported that longer residence times in soil and greater chloride loading resulted in higher retention and release rates, most likely due to ion exchange or organic matter (Bastviken et al. 2006). Unlike rain gardens, wetlands may be stratified, which can delay the natural lake cycle of mixing in the fall and spring, preventing oxygen from reaching the anoxic bottom and catalyzing eutrophication (Silver et al. 1996, Koretsky et al. 2011).

Most SCM research has focused on water quantity reduction and pollutant removal with an emphasis on phosphorus, nitrogen, and heavy metals (Carleton et al. 2000, Dietz et al. 2005, Flint and Davis 2007). In actuality, these concerns are dwarfed by the amount of road deicing salts entering the SCM. While rain gardens are advantageous for areas that do not have a lot of extra space to treat runoff, a constructed stormwater wetland requires a large land area and can process a large volume of runoff. This makes them advantageous where both water quantity and quality need to be improved, while also creating a long-lasting environmental habitat. While the wetland system does improve water quality, it has also been proposed that these systems may not be meeting their water quality improvement goals as some contaminants may not be mitigated due to bioaccumulation (Helfield and Diamond 1997).

A recent research project at Villanova (Forgione 2015) investigated the fate and transport of chloride ions entering the Villanova University Constructed Stormwater Wetland (CSW) between December 2011 and November 2015. This research evaluated the effluent concentrations of chloride at the CSW and whether these concentrations met the EPA chronic and acute standard criteria. The constructed stormwater wetland is located by the Villanova School of Law and is a retrofit of approximately 4050 square meters. This CSW replaced a conventional detention basin that was used to alleviate stormwater runoff during large storm events. The drainage area is 0.182 square kilometers; 53% of which are impervious surfaces (0.097 square meters). It was designed in 1999 as a unidirectional linear channel that flowed into a 12.2 by 12.2 square meter sediment forebay. After which the water flows into a series of meanders before reaching the outlet structure and further flowing into Mill Creek (Figure 4.8) (Forgione 2015).

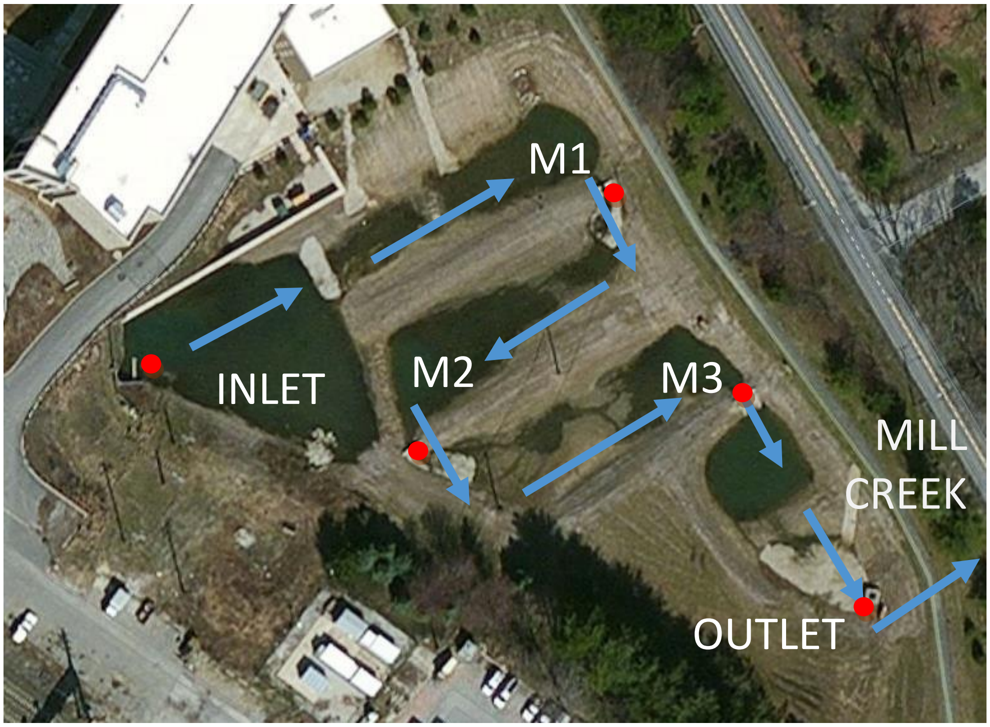

Figure 4.8. Villanova University's Constructed Stormwater Wetland showing flow paths with blue arrows and sampling locations marked with red circles (Forgione 2015, with permission)

The entire site is vegetated and originally planted with a range of native species, conversely, a salt tolerant invasive species, *Phragmites australis* (Type M), often overruns the native plants (Forgione 2015). Data were taken from storm events as well as baseflow events. The constructed stormwater wetland was sampled 40 times during the study period for storm events and 42 times for baseflows. Table 4.3 and Table 4.2 show the number events that meet the EPA criteria, how many exceed the chronic criteria, and how many exceed both chronic and acute criteria.

Table 4.2. CSM Storm Event Criteria Assessment (from Forgione 2015)

	Number of Events (n)	**Percentage of Events**
Meets both Criteria	31	77%
Exceeds Chronic Criterion	9 (*5)	23% (*13%)
Exceeds Both Chronic and Acute Criteria	4	10%
TOTAL:	**40**	**between chronic/acute*

Table 4.3. CSW Baseflow Criteria Assessment (from Forgione 2015)

	Number of Events (n)	**Percentage of Events**
Meets both Criteria	14	33%
Exceeds Chronic Criteria	28 (*23)	67% (*55%)
Exceeds Both Chronic and Acute Criteria	5	12%
TOTAL:	**42**	**between chronic/acute*

For storm events, 77% of these events met the EPA chronic criteria of 230 mg/L while 23% exceed it. Of the 23%, 10 of that has exceed the acute criteria of 860 mg/L as well. This data includes samples during all time of the year, but storms only effect the constructed storm water wetland about 13% of the year, thus baseflows are more revealing of a trend (Forgione 2015).

For baseflows, only 33% of these events met the EPA chronic criteria and 67% have exceed it with 12% exceeding the acute criteria (Forgione 2015). As it is harder to sample storms in the winter, perhaps if more storms were sampled during those months, more storm events would exceed the chronic and acute criteria as well.

To compare this to the rain garden, the EPA chronic criteria of 230 mg/L is approximately 0.41 PSU/ PPT. This means that the baseline of soil does not exceed the chronic criteria, but doing the winter months (Figure 4.6: 11/2012-4/2013, 12/2013-3/2014, 1/2015-3/2015), the water in the soil does. The groundwater does not seem to creep over the chronic toxicity except about once a year (7/2012, 6/2014, 8/2015).

4.4. Advection Flow of Chloride Ions

Advection is the bulk movement of a fluid or solutes from one location to another. As chlorides are considered a conservative tracer, using the seepage velocity equation will determine how quickly a chloride ion moves through soil to the groundwater, and from there how long it takes to get to the nearest water body of Hardings Run.

The equation used is shown by Equation 6, where v_s is seepage velocity, K is hydraulic conductivity, i is hydraulic gradient, and n is porosity. Hydraulic conductivity was obtained from borehole tests performed after the groundwater wells were installed in March 2012. Combining these results with mathematical modeling (Lee 2011) a vertical and horizontal hydraulic conductivity of 6×10^{-5} cm/s was selected for these calculations. In addition, the overall porosity of the soil was estimated as 0.3.

Equation 6.

$$v_s = \frac{K * i}{n}$$

Then using the velocity equation shown by Equation 7, the amount of time to get to the water body is calculated. In the equation, t is time, L is the bottom of the basin to the top of the groundwater table/ rain garden to the nearest water body (Hardings Run), and v is velocity.

Equation 7.

$$t = \frac{L}{v}$$

The time it takes for a chloride ion to reach the groundwater table is about 60 days and the time it takes for a chloride ion to reach Hardings Run, which is 0.27 kilometers away, is approximately 340 years (complete calculations are shown in the Appendix B).

Dye tracer studies (Neptune 2015) performed at the wetland were used to determine the t the residence time; which can be used to determine how long it will take for chloride ions move through the wetland during both baseflow and storm events. The time it takes for a chloride ion to move through the wetland into Mill Creek depends on the amount of water flowing through the system at the time. For example, during a storm event there is more precipitation and therefore a greater amount of flow. The mean time during a storm is approximately 49 hours +/- 19 hours (Neptune 2015). As there is less water flowing through the system during baseflow, its residence time is greater at 96 hours +/- 14 hours.

Both of these SCMS move chloride ions, but with completely different mechanisms and thus the time differences are significant. In the constructed stormwater wetland, chloride ions are a conservative tracer, moving through with little to no interaction at all with the structure and remaining in surface water. On the other hand, in the rain garden, chloride ions have more interaction with the soil, making it less effective as a conservative tracer and slowing down the time it takes to travel through to groundwater.

Chapter 5. Conclusions

In the US, it is estimated that 62.1 kilograms per capita of salt are used yearly to melt snow and ice off the roads (Stromberg 2014). Stormwater from impervious areas carries the salt placed onto impervious surfaces into receiving water bodies or stormwater control measures. For the rain garden analyzed in this research, the salts collected by the runoff can infiltrate to the water table.

Spikes in the salinity of surface water and soil occurred during cold weather, between December and March, while lower concentrations were observed during for the rest of the year. These spikes were caused by tens of metric tons of deicing salt being applied to the drainage area of the rain garden. Peaks in soil conductivity occurred almost immediately to a couple of weeks after a storm event, depending on the amount of precipitation and the temperature. The temperature is important because the water, and thus chloride ions, will not infiltrate through the soil when the soil is frozen. Elevated chloride levels persisted until mid to late summer (June-August). From the soil, the chlorides penetrated the groundwater.

Groundwater had slight seasonal variations in salinity that increased 4-5 months after the spikes in soil water. This indicates that it takes time for the chloride ions to be released from the soil and to accumulate in the groundwater. The groundwater salinity levels vary seasonally, but are slowly increasing over time. The average groundwater salinity is currently approximately 0.32 PSU/PPT. If one compares that value to that of seawater, which is defined as 35 PSU/ PPT, it will take around 75 to 100 years for the groundwater to reach that threshold at the current rate of increase.

Transportation departments throughout the US have started pursuing strategies to reduce their salt use as the harmful side-effects of its use become better understood. These alternative strategies include mixing salt with slight amounts of water to spread it out more or blending it with sand and gravel to provide more traction and allow the salt to stick more efficiently (Stromberg 2014). Other solutions include using beet juice, sugarcane molasses, or mixes with salt. While these alternatives do not completely eliminate the use for salt and most create their own set of problems, they do reduce the amount of salt used. Another alternative is to encourage the use of winter-specific tires on vehicles. While this requires swapping tires twice a year, less salt is needed on the roadways as the cars can handle a little more snow and ice. These solutions need to be realized and applied to start reducing the amount of salt going into the environment.

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Appendix A

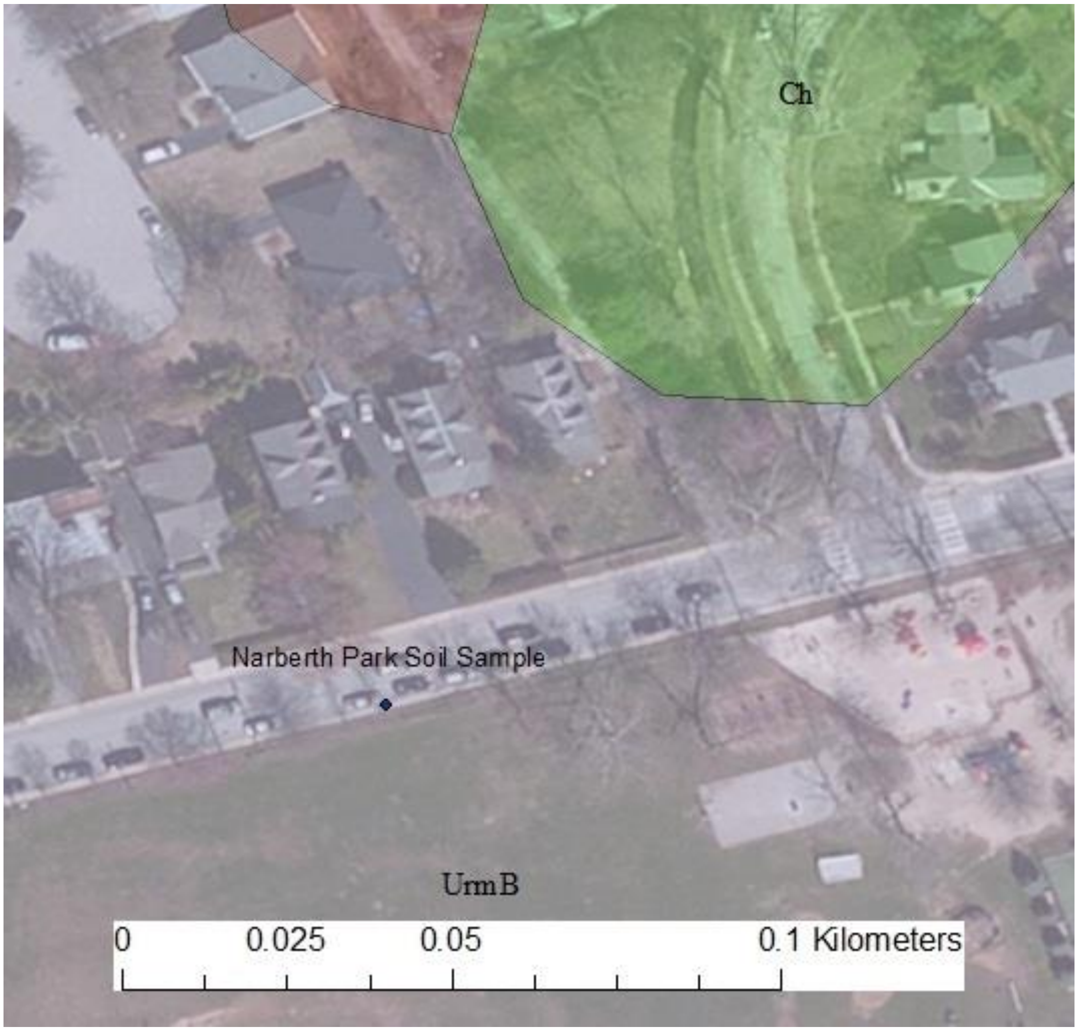

Figure 0.1. Narberth Soil Sample Location with USGS Soil Survey Overlay

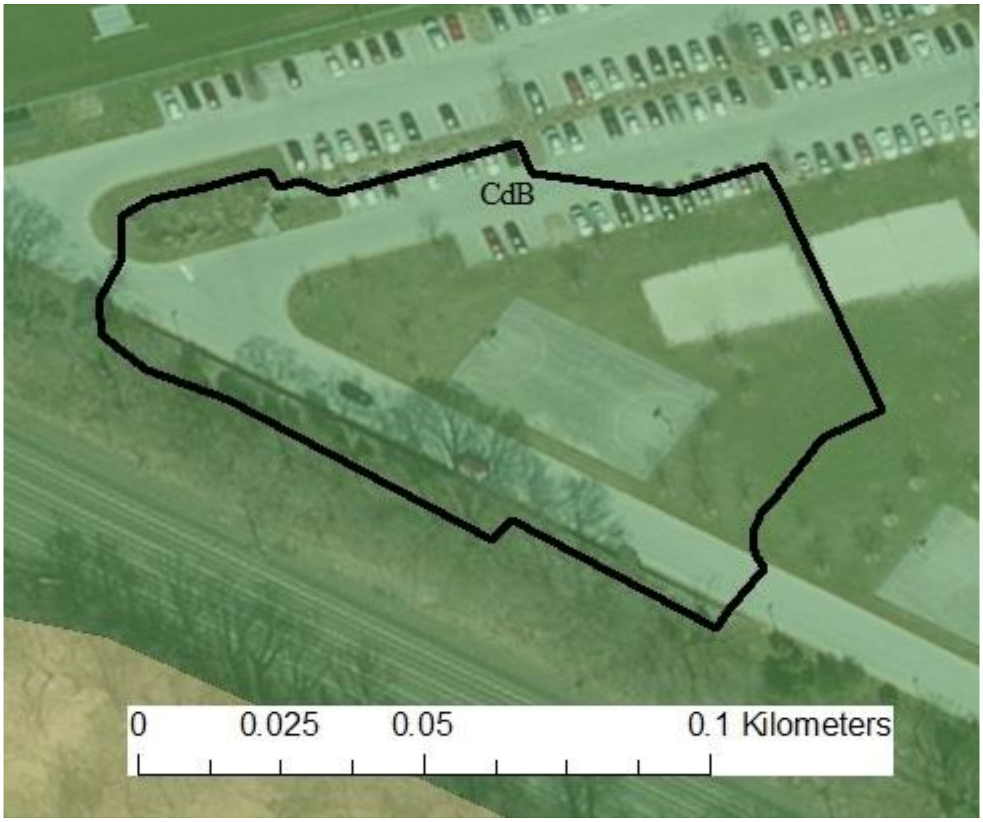

Figure 0.2. Villanova University Raingarden Drainage Area with USGS Soil Survey Overlay

Appendix B

Travel to Groundwater Table

$$v_s = \frac{K * i}{n} = \frac{(6 * 10^{-5}\ {}^{cm}/_{s}) * (1)}{0.30} = 2 * 10^{-4}\ {}^{cm}/_{s}$$

$$t = \frac{L}{v} = \frac{12\ m - 1.22\ m}{(2 * 10^{-4}\ {}^{cm}/_{s}) * \left(\frac{1\ m}{100\ cm}\right) * \left(\frac{60\ sec}{1\ min}\right) * \left(\frac{60\ min}{1\ hr}\right) * \left(\frac{24\ hr}{1\ day}\right)} = 62.5\ days$$

Travel to Nearest Water Body (Hardings Run)

$$v_s = \frac{K * i}{n} = \frac{(6 * 10^{-5}\ {}^{cm}/_{s}) * (0.0125)}{0.30} = 2.5 * 10^{-6}\ {}^{cm}/_{s}$$

$$t = \frac{L}{v}$$

$$= \frac{0.2677\ km}{(2.5 * 10^{-6}\ {}^{cm}/_{s}) * \left(\frac{1\ m}{100\ cm}\right) * \left(\frac{1\ km}{1000\ m}\right) * \left(\frac{60\ sec}{1\ min}\right) * \left(\frac{60\ min}{1\ hr}\right) * \left(\frac{24\ hr}{1\ day}\right) * \left(\frac{365\ days}{1\ year}\right)}$$

$$= 339.5\ years$$