



Exploring the Effect of Chloride from De-icing Salts on Heavy Metal Concentrations in Urban Soils: A Case Study in Halifax, Nova Scotia, Canada

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ABSTRACT

Established in 1749, Halifax has long been home to various factories and extensive military installations, and experienced the largest ever non-nuclear explosion. Still an active port city, Halifax soils variably reflect aspects of this history and its geological past. A pilot study by the 2013/2014 Environmental Geoscience class at Dalhousie University determined heavy metal concentrations in residential soils of the Halifax Peninsula. At each of over 30 residences, three samples were obtained: house dripline, roadside, and an ambient sample from an open location on the property. The samples were dried, sieved, and analyzed using X-Ray Fluorescence (XRF) for Pb, As, Cr, Cu, Zn, Ba, V, Cd, Co, Se, Mo, and Sn. In many cases, dripline values of some metals were greater than ambient values, which in turn were higher than roadside values.

One possible explanation for the lower roadside metal values is mobilization of metals by chloride from de-icing salts. Sodium chloride (NaCl) is particularly effective for anti-icing and de-icing in Halifax due to the moderate climate. The objective of this study is to explore the process of chloride leaching and its impact on metal mobility using soils from the Halifax Peninsula. Soil samples were collected to a depth of 10 cm, homogenized and sieved to <2 mm. For each sample, leaching experiments were done with controls of 0%, 3.5%, and 23% NaCl solutions to represent pure water, saline water, and brine, respectively. For each experiment, a 70 g (approximately 1 cm thickness) soil subsample was placed in a Buchner funnel with filter paper, and gently leveled. 565 mL of solution was poured through, to represent the annual average precipitation in Halifax scaled down by a factor of 10. For the 3.5% and 23% controls, 200 mL of the saline solutions were added, followed by 465 mL of distilled water. This is to account for the fact that salt loading occurs mostly from December to March, with approximately 36% of the total annual precipitation occurring in the winter months. Pre- and post-leaching heavy metal concentrations were analyzed using XRF to determine if metal concentrations had decreased as a function of salinity. Most soils with initially elevated metal concentrations showed a greater decrease in metals such as zinc and lead, with increased salinity. Decreased calcium concentrations with increased salinity suggests the occurrence of cation exchange. Gradual darkening of the leachate from the 0% to 23% controls suggests increased mobilization of organic matter with increased salinity.

Keywords: road salt, de-icing, chloride leaching, Halifax peninsula, soil, heavy metals

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DEFINITIONS AND ABBREVIATIONS

CCME – Canadian Council of Ministers of the Environment

USEPA – United States Environmental Protection Agency

XRF – X-ray fluorescence spectrometry

NaCl – sodium chloride

HRM – Halifax Regional Municipality

ARD – Acid Rock Drainage

EC – electrical conductance

TDS – total dissolved solids

CEPA – Canadian Environmental Protection Act

NSDNR – Nova Scotia Department of Natural Resources

DISP – Dalhousie Integrated Science Program

PS – pilot study sample

1Y – 1 year equivalent leaching

2Y – 2 year equivalent leaching

The terms “road salt” and “de-icing salt” will be used interchangeably throughout this document.

CHAPTER 1: INTRODUCTION

1.1 GENERAL STATEMENT

Studies have been done globally to examine the concentrations of certain heavy metals in residential soils by Foley et al. (2011) in St. John's, Newfoundland, Canada; Mielke et al. (2013) in New Orleans, Louisiana, USA; and Markus et al. (1996) in Glebe, Australia, to name a few. Most of these studies showed that the concentrations are typically well above guidelines deemed safe by agencies such as the Canadian Council of Ministers of the Environment (CCME), especially in older cities. A pilot study of this nature was carried out by the Environmental Geoscience class at Dalhousie University in the 2013/2014 academic year, which yielded thought-provoking results (Archibald et al., 2014).

Upon sampling approximately 30 residential properties in three locations including dripline (within 1 m from a house), ambient (open location of yard), and roadside (within 1 m from road), the students observed that many of the roadside samples consistently had lower concentrations of certain heavy metals when compared with their ambient and dripline counterparts. This was contrary to the prediction that roadside values would be higher than ambient values. For over half of the 21 residences at which all three sample types were obtained, metal concentrations in roadside samples were lower than in their ambient counterparts. Figure 1 shows the percentage of roadside samples with metal concentrations above, below, or equal to those of the associated ambient samples. Other metals showed similar trends. A possible explanation, which this study will explore, is that the lower values in the roadside soils represent metal mobilization by chloride from road salts (Archibald et al., 2014), a process known as chloride leaching.

1.2 OBJECTIVE AND IMPORTANCE

The purpose of this study is to explore the effect that the application of de-icing salts, namely sodium chloride, have on concentrations of particular heavy metals in soils from the Halifax Peninsula.

This is a case study of Halifax, Nova Scotia, Canada, an old city relative to other urban areas in Canada, and one with a significant industrial history associated with various industrial, military and port activity, and the Halifax Explosion. The history of the Halifax Peninsula and its influence on the local soils will be discussed in chapter two.

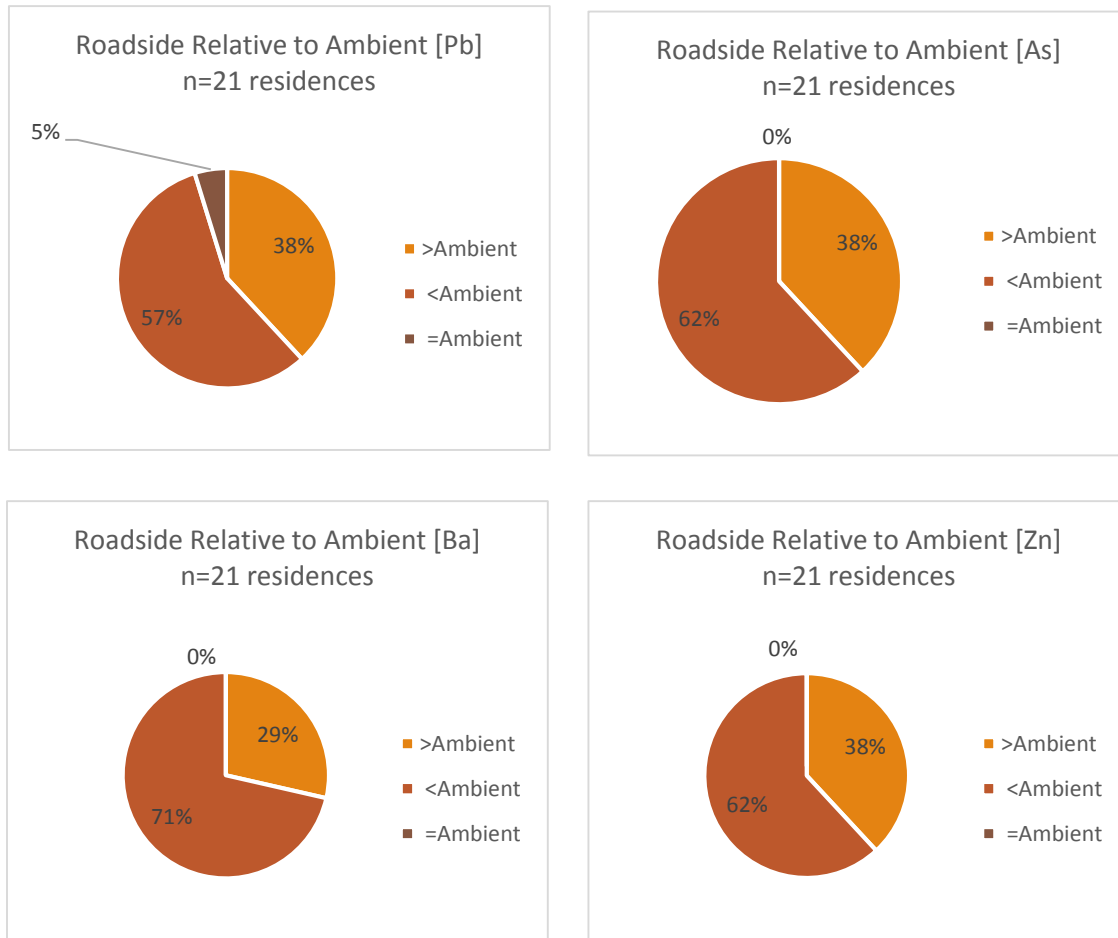


FIGURE 1: % OF RESIDENCES WITH ROADSIDE METAL CONCENTRATIONS [ABOVE, BELOW, OR EQUAL TO] RELATIVE TO AMBIENT METAL CONCENTRATIONS

During the winter months in Halifax the roads become covered in ice due to a combination of sub-zero temperatures and precipitation events. This makes it critical to ensure the safety of the human population by employing de-icing strategies. A common procedure is the application of salt, which is a cheap and effective de-icer, provided temperatures are above -11°C . De-icing salts facilitate economic productivity and human safety when road conditions are poor, but also have various associated environmental impacts.

Chloride leaching is a process which is better understood in the context of mining and its interaction with ore-bearing rocks. For example, chlorine can be used in the extraction of gold as a safer substitute for cyanide in the leaching process (Ximing et al., 1992). This study will aim

to build a better understanding of the role of chloride leaching within an urban environment, focusing on the impact on metals in soils by chloride from road salts.

Urban soils contain various contaminants, including metals, which may pose a risk to human health, depending on bioaccessibility. Guidelines for many of these metals have been set by the CCME, and as is common in other older cities, for example St. John's, Newfoundland (Bell et al., 2010; Foley et al., 2011), these values were commonly exceeded in the residential soils used in the pilot study. One such contaminant is lead, which can have impacts not limited to neurodegenerative, cardiovascular, and reproductive effects. Since 1978/79, blood lead levels in Canadians have decreased by over 70% as a result of the implementation of measures to reduce exposure, such as the removal of lead from paint and gasoline (Health Canada, 2013). Lead, zinc, arsenic and copper can be found in high concentrations in soils in St John's and Halifax, both of which are relatively old cities. Spatial concentration patterns in St John's by Foley et al. (2011) suggests weathered paint, combustion of coal, and vehicle emissions to be major sources of these metals.

With worries about contaminants such as lead in urban soils and their possible effects on human health some may misinterpret this study as suggesting that the leaching of heavy metals by salt is beneficial. However, increased salinity brings forth a suite of other potential problems, such as degradation of groundwater and soil quality, which can propagate further detriment to the environment (Bester et al., 2006).

1.3 OVERVIEW

The suggestion made by Archibald et al. (2014) that road salts could be decreasing the heavy metal concentrations is the focus of this study. Chapter two will provide background information on history that may influence the chemistry of Halifax soils. This will be followed by a summary of the pilot study and similar case studies. Next, de-icing procedures in Halifax and the process of chloride leaching will be discussed.

In chapter three the methods used in this study will be discussed. This includes the sampling procedure, characterization of soil parameters and sieving, leaching experiments, and the geochemical analysis.

Chapter four will contain the results of the geochemical analysis, which will be discussed in chapter five. Chapter six will provide conclusions and recommendations for future work.

CHAPTER 2: BACKGROUND

2.1 STUDY AREA

The geographic focus of this study is the Halifax Peninsula, Nova Scotia, Canada, as seen in Figure 2.

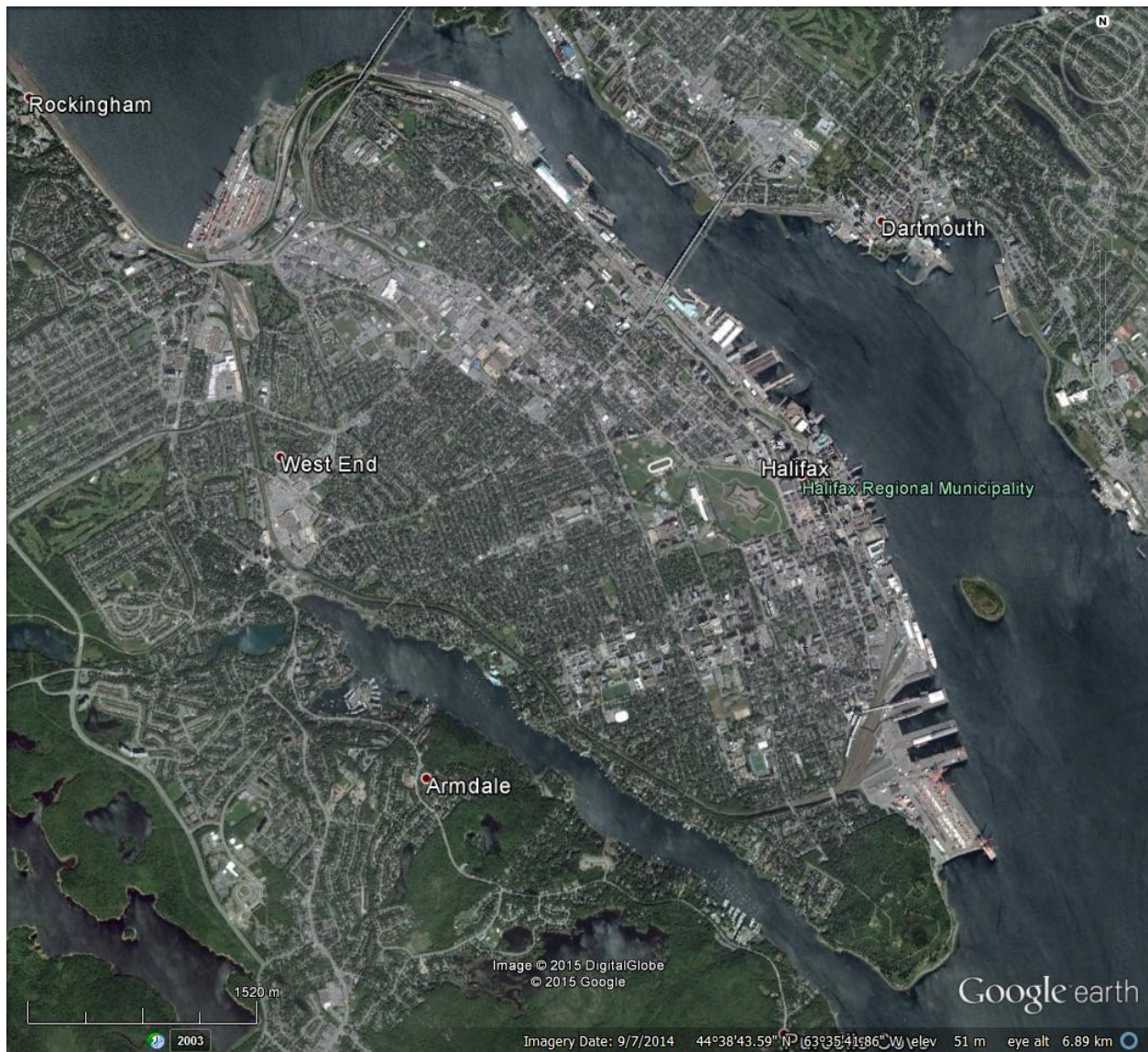


FIGURE 2: HALIFAX PENINSULA. 44°38'43.59"N 63°35'41.86"W. GOOGLE EARTH. SEPTEMBER 7, 2014. MARCH 16, 2015.

2.1.1 GEOLOGY OF THE HALIFAX PENINSULA, NS, CANADA

Exposed bedrock and Quaternary glacial features such as drumlins and till veneer are found on the Halifax Peninsula together with anthropogenic fill. The drumlins were deposited as a result of glacial advance during the last Ice Age, which peaked in the late Pleistocene. They have proven to be useful locations for forts, and also for farming due to the fertility of the soils that later developed on them. (Donohoe et al., 2005)

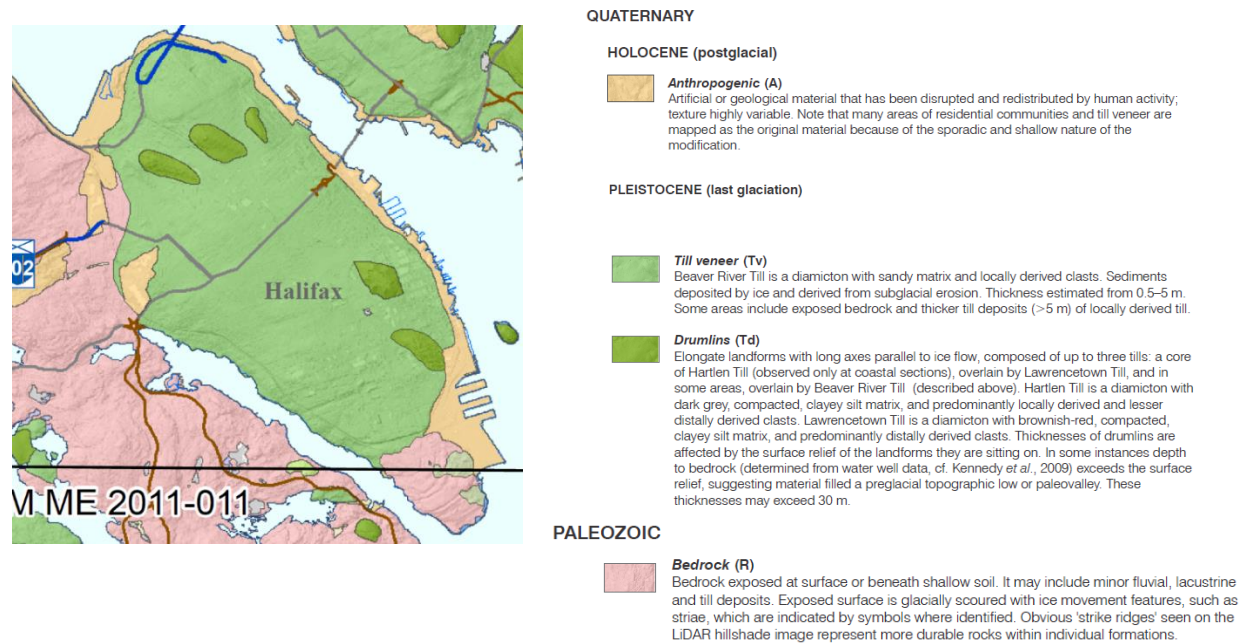


FIGURE 3: SURFICIAL GEOLOGY OF HALIFAX. COMPILED BY UTTING, 2011.

Cambrian to Ordovician slate and minor metasiltstone of the Halifax Group largely comprise the bedrock geology of the Halifax Peninsula. Underlying the Halifax Group is the Goldenville Group, which consists of metasandstone, minor metasiltstone, and slate of late Neoproterozoic to Cambrian age. (Donohoe et al., 2005) Together the Halifax and Goldenville Groups make up the Meguma terrane. Metasediments of both groups are found on the Peninsula due to steep folds produced during the Neocadian orogeny (Waldron et al., 2015). Four formations have been identified on the Peninsula (White et al., 2008). The Halifax Group comprises the Bluestone Quarry Formation, which is the uppermost pre-Quaternary stratigraphic unit on the Peninsula; and the Cunard Formation. The Goldenville Group comprises the Beaverbank and Taylors Head Formations (White et al., 2008; Waldron et al.,

2015). The slates contain abundant iron-sulphide minerals, up to 10% in some locations, with pyrite and pyrrhotite dominant; and arsenopyrite, cobaltite, glaucodot, chalcopyrite, and covellite in lesser amounts (Haysom, 1994). These minerals have associated detrimental effects upon exposure to the atmosphere, including acid rock drainage (ARD) (Fox, 1999; Goodwin, 2003) (Figure 4), which may interact with the surrounding soils and introduce elements such as sulfur and arsenic and possibly heavy metals. The Halifax Group has been identified as having a high potential of developing ARD. This is largely attributable to monoclinic pyrrhotite, which is known for causing ARD being the dominant sulphide mineral (Fox, 1999).

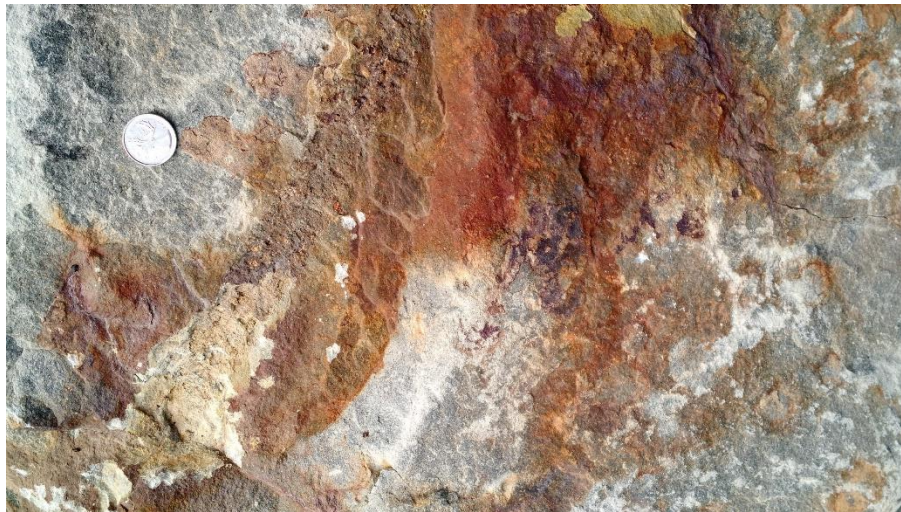


FIGURE 4: EVIDENCE OF ACID ROCK DRAINAGE (HALIFAX GROUP), POINT PLEASANT PARK.

2.1.2 SOIL TYPES OF NOVA SCOTIA

As the bedrock and glacial deposits influence the fertility of the soil, the geology of the Halifax Peninsula is a key factor in determining local soil types. Soil type is the result of the interaction between parent material, climate, organisms, and topography over time (Jenny, 1941; Nova Scotia Museum of Natural History, 1996)

Nova Scotia soils have been forming since the end of the last Ice Age 10,000 years ago. Due to the breakdown of bedrock through glaciation in combination with the humid climate and relatively warm post-glacial period, soil formation has been reasonably productive (Nova Scotia Museum of Natural History, 1996).

A soil type survey undertaken by Nova Scotia Department of Natural Resources (Keys, 2007) states that soils in the Halifax region are expected to be “fresh, medium to coarse-

textured soils, with near-surface soil texture dominated by sandy loam or coarser textures” (p.8) referred to as ST2, and to a lesser extent ST2-L soils, which are similar to the aforementioned, but with surface soils dominated by loam or silt loam. Drainage in these soil types is typically good, however this can vary with factors such as slope, thickness and permeability (Keys, 2007).

Figure 5 is from a map of a soil survey done in Halifax in 1963. The soils on the peninsula belong to three soil series: Bridgewater (Bw), Halifax (Hx), and Wolfville (Wv). Characteristics of these series are similar to those described in the NSDNR’s survey, with shaly loam dominant (Bw), followed by sandy loam (Hx), loam (Wv), and sandy clay loam (Wv). All series have good drainage. All soils used in this study belong to the Bridgewater series, in which shaly loam is dominant (MacDougall et al., 1963). Field identified soil type for samples in this study are listed in the appendix.

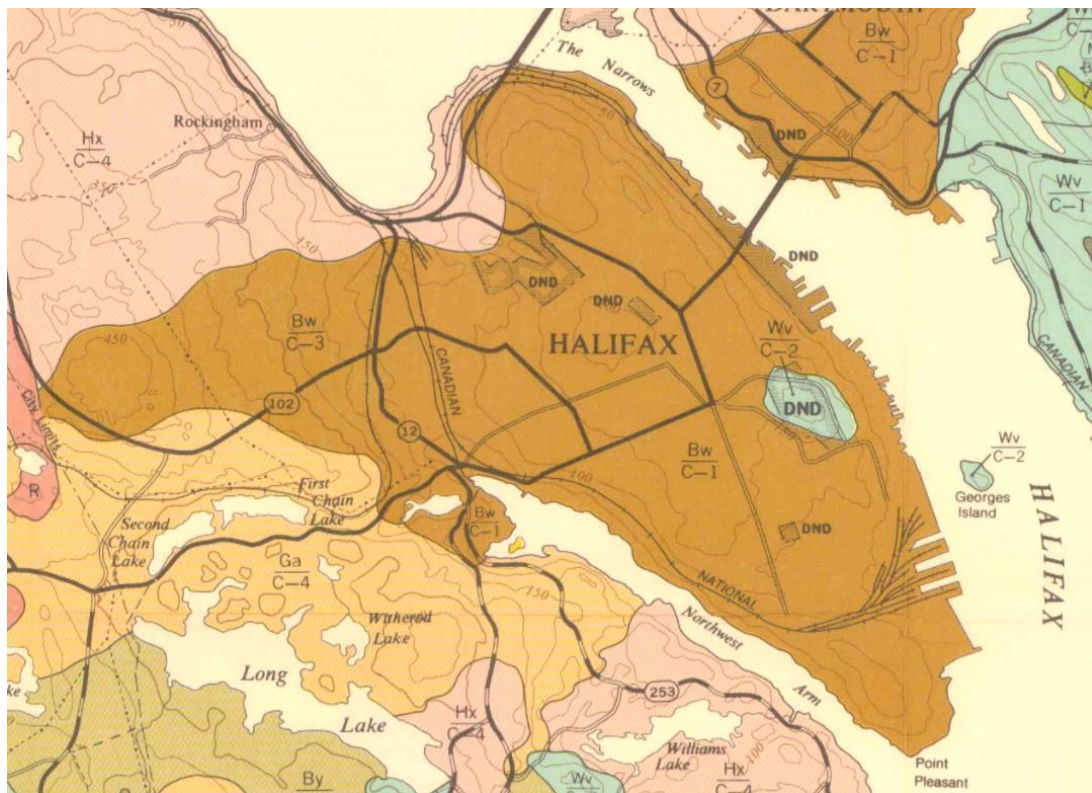


FIGURE 5: SOIL SERIES MAP. BROWN (BW); PINK (HX); BLUE (WV). MODIFIED FROM MACDOUGALL ET AL., 1963.

2.2 HISTORIC SIGNATURES IN THE SOILS

In addition to the geologic and geographic factors that influence soil characteristics, an older city such as Halifax will have a fair amount of anthropogenic history represented in its soils. These effects include fertilizers from farming, metals from cemeteries (Jonker & Olivier, 2012), a variety of pollutants from factories, fly ash with associated metals, from coal burning (US EPA, 2010) and lead from gasoline and paint. This anthropogenic signature is prominent in many soils.

2.2.1 INDUSTRY AND MILITARY

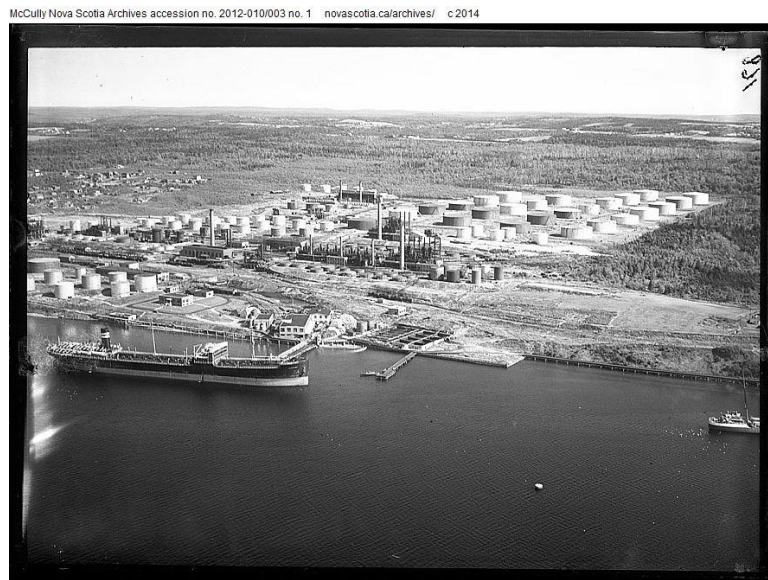


FIGURE 6: IMPERIAL OIL REFINERY (DARTMOUTH) WITH TANKER IN FOREGROUND. MCCULLY, 1931.

Following the establishment of Halifax in 1749, Halifax served for over 150 years as a dockyard and a garrison city for the Imperial army and navy. In the early 1900s as tension grew between Germany and England, England recalled its troops, and by February 1906 (p. 26, *The Town That Died*) the garrison was completely withdrawn from Halifax, leaving only military equipment in abandoned barracks, a “lifeless dockyard,” and a dwindling economy. Thus began the accelerated rise of new industries in Nova Scotia, and “the development of harbour and port facilities” by the Canadian government (p.27, *The Town That Died*)

Halifax Shipyards has remained an active industry for over a century, having been founded in 1887. Figure 7 shows lathe workers at the shipyards in 1956.

In 1914, England declared war on Germany. With this, the military presence again began to thrive in Halifax. Halifax became a port for the Royal Navy as well as “thousands of allied cargo ships”, which fueled the local economy. Factories became prominent, including for “sugar, textiles, iron, steel and other manufactured goods” (p. 29, *The Town That Died*), and the shipyards were booming with business.

Today there remains military and shipping activity on the peninsula (Figure 8), among other industries.

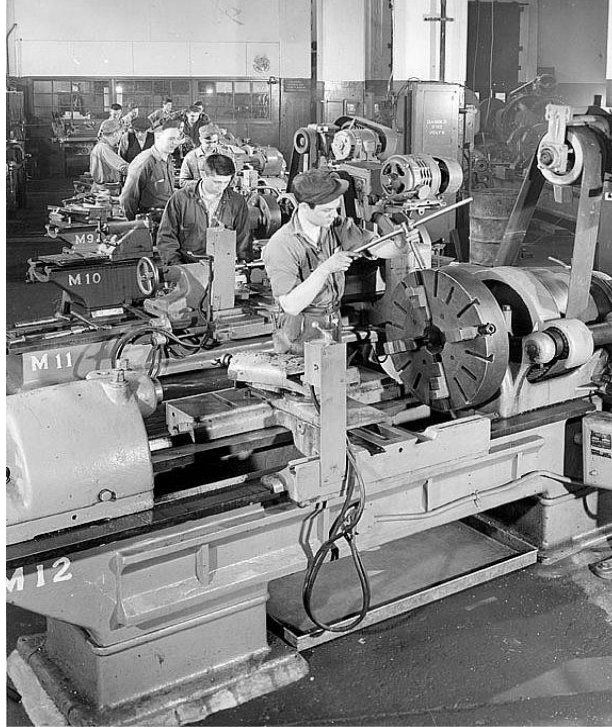


FIGURE 7: HALIFAX SHIPYARD LATHE WORKERS. NOVA SCOTIA BUREAU OF INFORMATION, 1956.

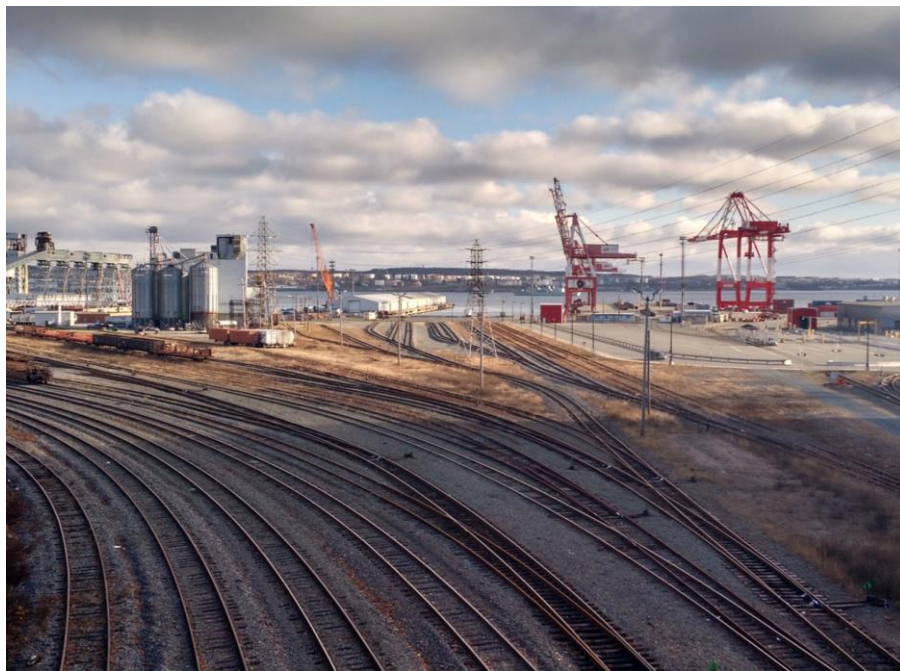


FIGURE 8: ACTIVE INDUSTRY IN SOUTH HALIFAX. ENE VIEW FROM YOUNG AVE. BRIDGE.

2.2.2 ENERGY GENERATION: COAL BURNING

Since the Industrial Revolution, coal has been a prominent source of energy due to its relative affordability, accessibility and abundance. Globally, coal still accounts for approximately 35% of electricity output (Environment Canada, 2013). In 2006, coal accounted for 80% of energy generation in Nova Scotia. Prior to the 1970's, imported oil was the primary source of electricity in Nova Scotia. Since then, coal has been the dominant source for electricity generation. The dominance of coal is declining, being replaced with natural gas and renewable sources, due to environmental and economic considerations. According to Nova Scotia Power, 60% of the provinces electricity still comes from coal as of 2014. Nova Scotia Power operates four coal power plants. Prior to 1999 the coal was sourced in Nova Scotia, however today it is sourced mostly from international mines. The remainder of energy generation comes from various sources including natural gas, oil, and wind (see Figure 9). The amount of energy generated in Nova Scotia using renewables has been increasing since the implementation of the provincial Renewable Energy Standard in 2007 (Nova Scotia Power, 2015).

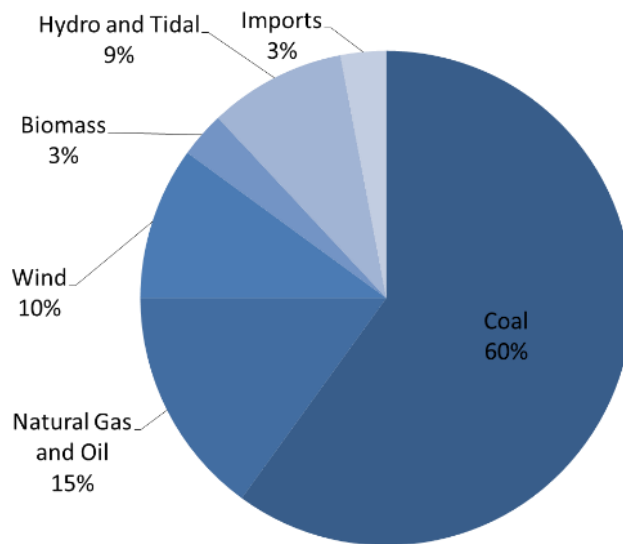


FIGURE 9: 2014 ELECTRICITY GENERATION BREAKDOWN. NOVA SCOTIA POWER, 2015.

The combustion of coal produces waste including fly ash, which is the fine particulate matter emitted. Coal burning is a major source of contaminants such as particulate matter, sulphur dioxide, nitrogen oxides, metals, other greenhouse gases and mercury. For the purpose of this study we will only consider the heavy metals emitted, which may be deposited in soils. Heavy metals such as arsenic, lead, mercury, cadmium, chromium, selenium are found in coal

ash. Such contaminants can pose a risk to human health as they are known carcinogens and can cause problems with the nervous system, heart, respiratory system, kidneys, reproductive system, gastrointestinal system, bone growth, and birth defects. Arsenic is the top contaminant from coal ash, but cadmium and lead also pose a significant risk (US EPA, 2010).

Contaminants from recent coal emissions are likely not found in soils of the Halifax peninsula, as the coal-fired plants are located in the north of the province (one in Trenton, three in Cape Breton. It is possible that emissions from the Tufts Cove Generating Station (see table), in Dartmouth may be wind-transported and deposited in Halifax soils, along with residues from historical coal burning in the city). Deposition depends in part on the prevailing wind direction, and therefore study of the soil geochemistry in Dartmouth is recommended. Today at Tufts Cove, electricity can be generated using imported oil or natural gas sourced from offshore Nova Scotia (Nova Scotia Power, 2015).



FIGURE 10: TUFTS COVE SMOKESTACKS. NOVA SCOTIA POWER, 2015.

TABLE 1: 2003-2007 METAL EMISSIONS FROM TUFTS COVE GENERATING STATION. DATA FROM ENVIRONMENT CANADA, 2013.

	As	Pb	Ni	V
Units	tonnes	tonnes	tonnes	tonnes
Year				
2007	N/A	N/A	N/A	6.1
2006	N/A	N/A	2.8	7.4
2005	5.8	6.1	3.2	9.2
2004	15	35	9.2	35
2003	14	48	9.1	20

It is difficult to pinpoint transported emissions from electricity generation as a source of soil contamination with certainty, however they are important to consider as potential contributors. In the pilot study on the soils of the Halifax Peninsula, at least one site was selected based on the presence of coal ash, and contained higher concentrations of elements such as sulphur and arsenic as well as heavy metals, than other samples from the property.

Coal fly ash may also have been introduced to soils intentionally, as it is a known source of nutrients including calcium, iron, copper, and zinc, which are essential to plant life. (Shaheen, 2014). A review by Pandey and Singh (2010) found that several studies showed that in low doses, fly ash can improve soil properties, but in high doses it can lead to heavy metal pollution and negatively impact soil microbes.

2.2.3 HALIFAX EXPLOSION

At the peak of the war boom, Halifax was experiencing “cargo traffic in excess of seventeen million tons” compared with the mere two million tons it was fortunate to receive prior to 1913. (p. 8, *The Town That Died*). On December 6, 1917 Halifax endured the largest manmade explosion prior to the atomic bomb.

In the narrows of the Halifax Harbour, Norwegian ship, *Imo*, carrying supplies for Belgian relief, ripped into the *Mont Blanc* and a “shower of sparks” (p.23, *The Town That Died*) ignited the French munitions ship. Those who knew what the ship was carrying were aware of the disaster that was upon them, yet were helpless as thick black smoke filled the air. The cargo of the French munitions Ship *Mont Blanc* was recorded as 2,300 tons of picric acid, 200 tons of TNT, 35 tons of benzole, and 10 tons of gun cotton. (p. 6, *The Town That Died*)

The French ship floated ashore and ignited the pier (p. 44, *The Town That Died*) and at 9:06 am, that sombre December 6th, the *Mont Blanc* exploded, disappearing into a “ball of flaming gases” with “blast waves from the exploding chemicals striking out at Halifax and Dartmouth with the violence of a hundred typhoons...wooden piers erupted and the sea boiled...wooden buildings were punched away, and those of concrete crumbled and fell “ (p. 53, *The Town That Died*) With fractured roads and uprooted trees, the city was in a state of devastation with a recorded death toll of 1, 946 people (Nova Scotia Communities, Culture and Heritage, 2010) . The pressure was so great that the *Mont Blanc*'s anchor was thrown 2 miles inland (p. 54, *The Town That Died*). Then came the “fury of the sea” (p. 56, *The Town That Died*) which flooded the land and created even more chaos.



FIGURE 11: COLLAPSED BUILDINGS (NS CAR WORKS) ON CLIFTON ST., HALIFAX. GAUVIN & GENTZEL, 1918.

As Michael J. Bird states in his chronicle, *The Town That Died*, “It would live again, but for a moment in history, the city’s heart stopped beating” (p.82). With a disaster of this magnitude, and at the time in history, it is difficult (if not impossible) to find literature regarding the impact to the natural environment. The explosives themselves could have contributed elements including carbon, hydrogen, nitrogen and oxygen to the soil, however debris and damaged infrastructure may have contributed significant amounts of metals. The devastation to the infrastructure (see Figure 11 & Figure 12) and the people of Halifax are clear, melancholy, and well-documented, and it is reasonable to assume that this event has, too, left its mark in the soils.

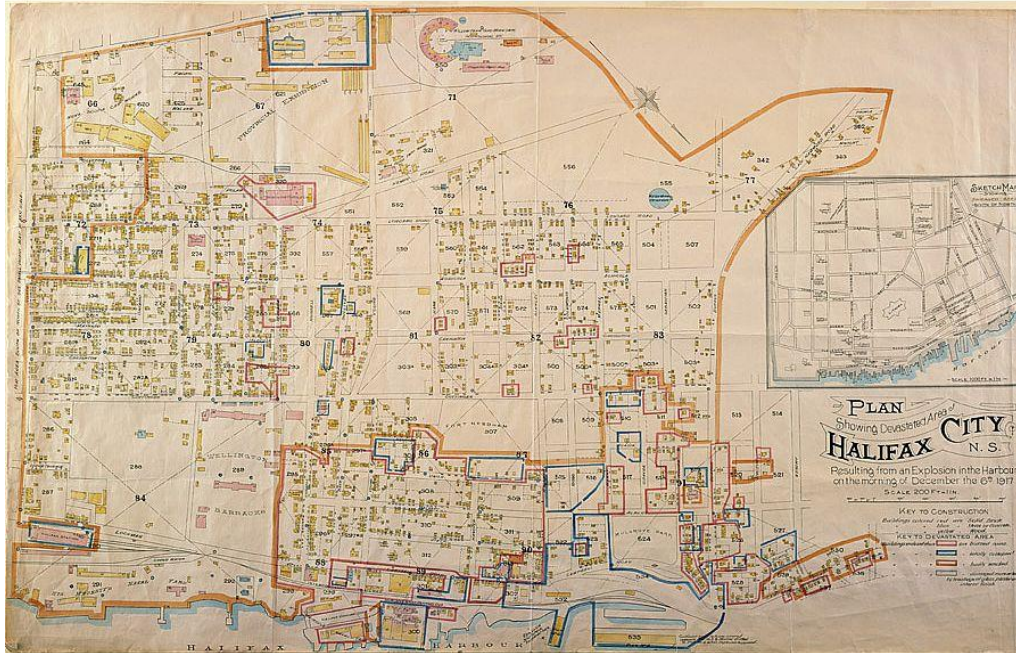


FIGURE 12: MAP OF DEVASTATION FROM HALIFAX EXPLOSION. NOVA SCOTIA BOARD OF INSURANCE UNDERWRITERS, 1918.

2.2.4 LANDFILLS: AFRICVILLE

The North end of Halifax has been virtually untouched with respect to analyzing residential soil geochemistry. There are several considerations, both geologic and anthropogenic that would make this area an important locale for geochemical hazard mapping. Geologically, the north of the peninsula comprises the Goldenville formation, which will likely make the soil geochemistry naturally distinct from that of the soils that overlie the Halifax formation. From the 1940's to the 1960's the north end held a community, Africville, which did not have access to municipal services such as water and sewage, and bordered the civic landfill for many years.



FIGURE 13: AFRIVILLE WELL. THE COMMUNITY DID NOT RECIEVE MUNICIPAL SERVICES.
BROOKS, CA. 1965.

It has been documented that residues from municipal solid waste landfills cause elevated levels of heavy metals including arsenic and cadmium (Jain et al., 2004). MacPherson (1987) found that Nova Scotia soils were vulnerable to the substandard landfill practices of the past, which introduced heavy metals and synthetic compounds to soils and waters through the leachate. Figure 14 demonstrates the importance of knowing the geochemistry of soils, as soil contaminants can pose a risk to humans if ingested.

None of the soils analyzed in this study, or the associated pilot study came from this area of the Peninsula, and further study is therefore recommended.



FIGURE 14: CHILDREN GATHERING BLUEBERRIES IN AFRICVILLE. BROOKS, CA. 1965.

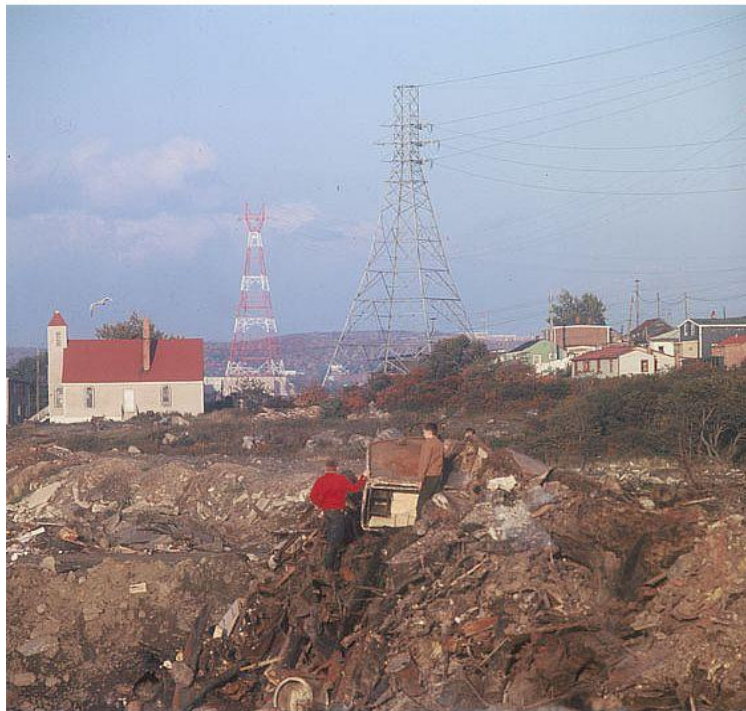


FIGURE 15: HALIFAX CITY DUMP. AFRICVILLE IN BACKGROUND. BROOKS, CA. 1965.

2.2.5 LEADED PAINT AND GASOLINE

Lead is a problematic contaminant commonly found in older cities. For example, Schwarz et al. (2012) found that 53% of 61 residential properties in Baltimore (founded 1729) exceeded the USEPA 400 ppm guideline for lead in residential soils. Furthermore, 81% of ambient residential soils in Halifax (founded 1749), albeit a small number of samples (n=30) (Archibald, et al., 2014); and 51% of residential samples from St John's (founded 1497) (Bell et al., 2010) had lead concentrations exceeding 140 ppm, the CCME guideline.

Lead is found in higher concentrations as a function of building age and proximity to the building. (Bell et al., 2010; Schwarz et al., 2012; Archibald et al., 2014) This has been attributed to the use of lead-based paints. Prior to the 1960s, household and industrial paints contained 10% to 50% lead (Environment Canada, 2013). Although legislation has limited the use of lead in paint, weathering of, or improper removal of, lead-based paint can introduce it into the adjacent soils. Jacobs (2003) emphasizes the need for safe practices when disturbing lead-based paint, with consideration of the high cost of decontamination along with the risk of lead-poisoning.

Another source of lead is the use of leaded gasoline, prior to the introduction of unleaded gasoline in 1975 and the prohibition of leaded gasoline in the 1990s.

2.2.6 OTHER ANTHROPOGENIC SOURCES OF METALS

Other potential sources of contaminants include, but are not limited to, industries such as shipbuilding, pesticides (although many no longer used in Halifax) and fertilizers, treated wood for infrastructure, and cemeteries.

2.3 IMPORTANCE OF SOIL GEOCHEMISTRY STUDIES

Just as it is clear that human activity has an impact on soil health, soils can also impact human health. A contaminant of particular concern is lead, as even in low concentrations it has associated health effects. Infants and children are particularly vulnerable to the effects of lead due to their "greater gastrointestinal absorption, less effective renal excretion, and different behaviour patterns than adults, such as the ingestion of non-food items" (Health Canada, 2013). In New Orleans it has been documented that high blood lead levels in children are associated with high lead concentrations in soils (Mielke et al., 2013).

Soils can enter homes by being tracked in on shoes or by wind transport through an open window, and high-lead dust can accumulate and consequently be inhaled by the residents. Rutz et al. (1997) determined experimentally that 20-30% of lead found in household dust came from contaminated soil outside.

In addition to accidental ingestion, exposure to metals may result from the consumption of vegetables grown in contaminated soils (Chaney, 1984). A study done in the HRM by Heidary-Monfared (2011) found that over one-third of soil samples from current and potential gardens have concentrations of Cu, Pb, Zn, and As exceeding the CCME guidelines, and stated the importance of maintenance of raised garden beds to minimize contamination from adjacent areas. Bacigalupo & Hale (2012) developed a probabilistic screening tool to estimate exposure to lead and arsenic through consumption of homegrown vegetables, as well as incidental ingestion of soil and dust. They found that for people who consume a large amount of homegrown vegetables the risk of arsenic exposure from consumption can be as significant as incidental ingestion. Clark et al. (2008) found produce consumption to account for only 2-3% of lead exposure, whereas 72-91% is attributed to soil ingestion. However, it is important to note that the concentration of lead in the surrounding environment may not reflect the concentration of a metal that will end up in the blood stream or the toxicity thereof, as it depends on the factors including the metal form, solubility, and bioaccessibility.

2.4 PILOT STUDY

In the fall semester of 2013, the Environmental Geoscience class at Dalhousie University executed a pilot study looking at the concentrations of heavy metals with CCME guidelines in residential soils in the Halifax Peninsula (Archibald et al., 2014). Heavy metals can be introduced to the soil as point or non-point sources.

The students collected 120 samples of the top 15 cm of soil, from three locations at each of thirty residences on the Halifax Peninsula (see Figure 16 for site locations). The three locations were dripline (within 1 m of house), roadside (within 1 m of road), and an ambient sample from an open location in the yard (see Figure 17). At some properties it was not possible to obtain all three sample types, however all three were taken from 21 of 30 properties. The samples were then laid out to air dry over several days, sieved to <1mm, and analyzed for heavy metal concentrations using an Olympus X-5000™ portable XRF. The metals of focus for

the pilot study were those that have CCME guidelines, and included Pb, As, Cr, Cu, Zn, Ba, V, Cd, and Co, Se, Mo, and Sn.

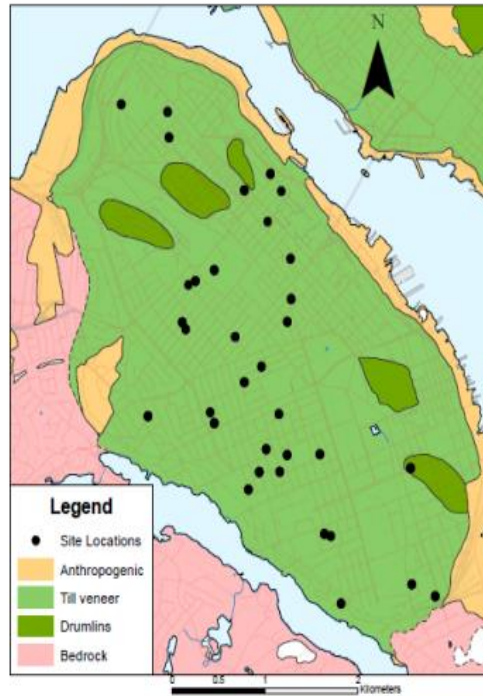


FIGURE 16: SAMPLE SITE LOCATIONS. (ARCHIBALD ET AL., 2014)

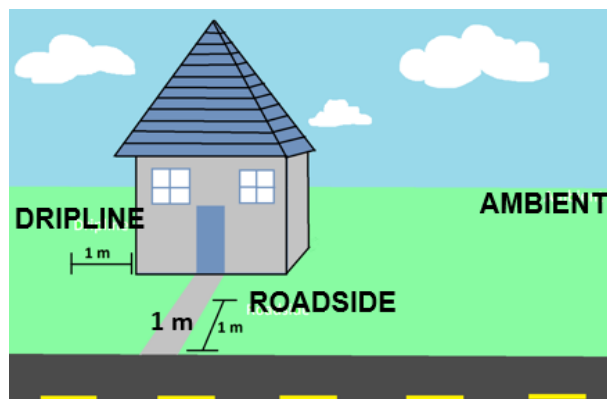


FIGURE 17: RESIDENCE SAMPLE LOCATION TYPE

2.4.1 GENERAL FINDINGS

Pb, As, Cr, Cu, Zn, and Ba commonly exceeded CCME guidelines (see Figure 18), with Cd, V, Co, Se, Mo, and Sn rarely exceeding the guideline limits. Lead has a CCME guideline of 140 ppm, and 81% of ambient samples exceeded this value, with a range from of 17-1751 ppm.

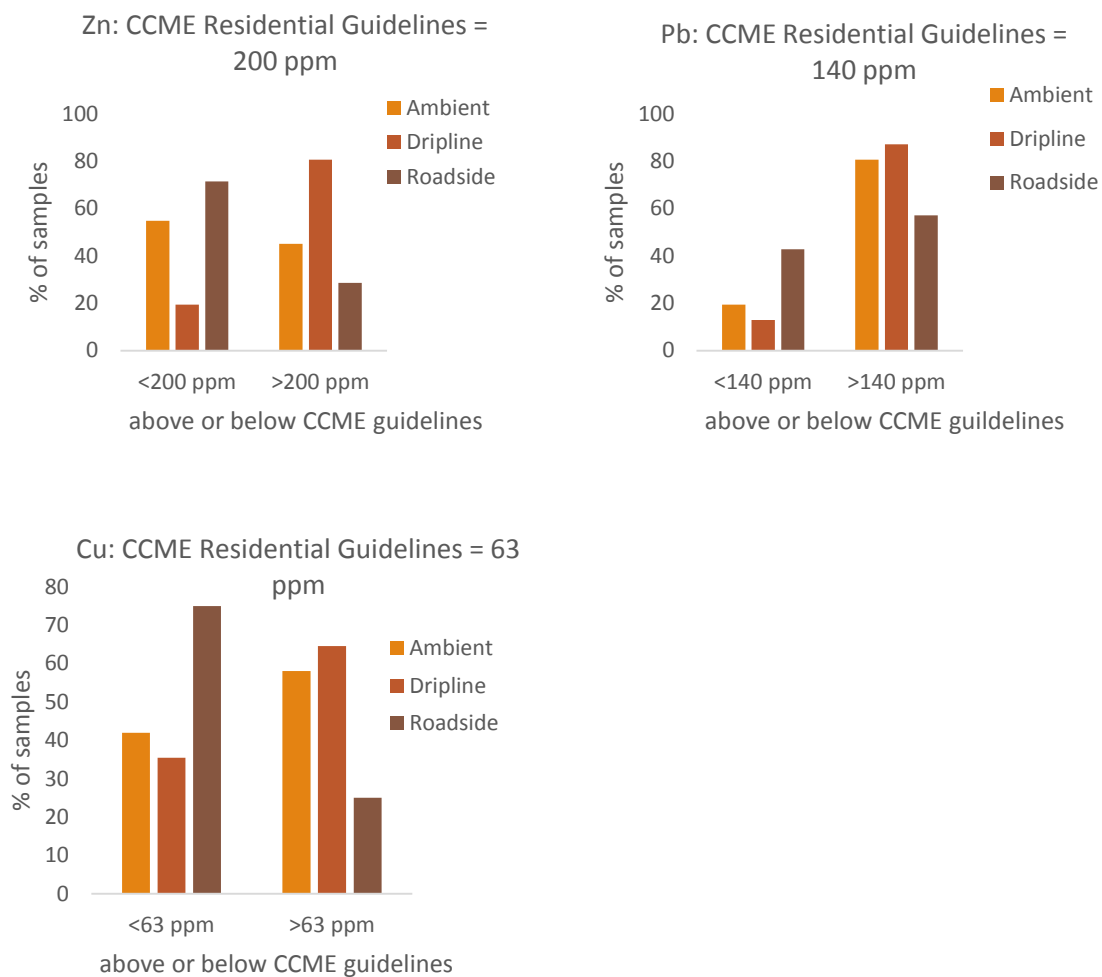


FIGURE 18: PERCENTAGE OF SAMPLES ABOVE/BELOW CCME GUIDELINES FOR ZN, PB, CU IN RESIDENTIAL SOILS. (ARCHIBALD ET AL., 2014)

2.4.2 FINDINGS RELEVANT TO THIS STUDY

As demonstrated in Figure 18 and Figure 19, a lower percentage of roadside samples are above CCME guidelines for the given metal, compared with a higher and moderate percentage of dripline and ambient samples, respectively. This trend can be observed for all six of the metals shown in Figure 18 and Figure 19 and has been proposed to be possibly attributable to chloride leaching from road salts (Archibald et al., 2014). Salt management in the HRM and the process of chloride leaching will be discussed in subsequent sections of this chapter.

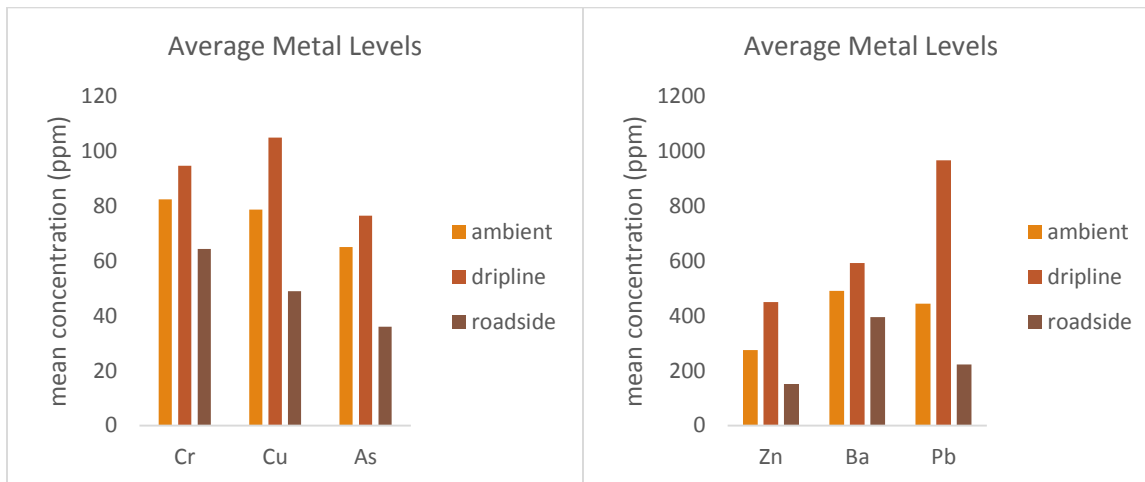


FIGURE 19: AVERAGE METAL CONCENTRATIONS FOR ROADSIDE SAMPLE WERE COMMONLY LOWER THAN ASSOCIATED AMBIENT CONCENTRATIONS. (ARCHIBALD ET AL., 2014)

2.5 CASE STUDIES FROM ELSEWHERE

Comparing the Halifax study with Bell et al. (2010) for St. John's, Newfoundland, the locations (which are fairly close geographically) exhibit a similar trend in that the median levels for lead in roadside soils are lower than that of dripline and ambient (see Figure 20). It should be noted that the total number of samples in the Halifax area is low ($n=90$). In contrast, for a similar study in New Orleans, the median lead values for roadside are lower than dripline and higher than ambient for inner cities, and higher than both dripline and ambient for the suburbs (Mielke et al., 2013). New Orleans has a significantly warmer climate than Nova Scotia or Newfoundland, and thus would not have to utilize de-icing salts, which could account for the different trend.

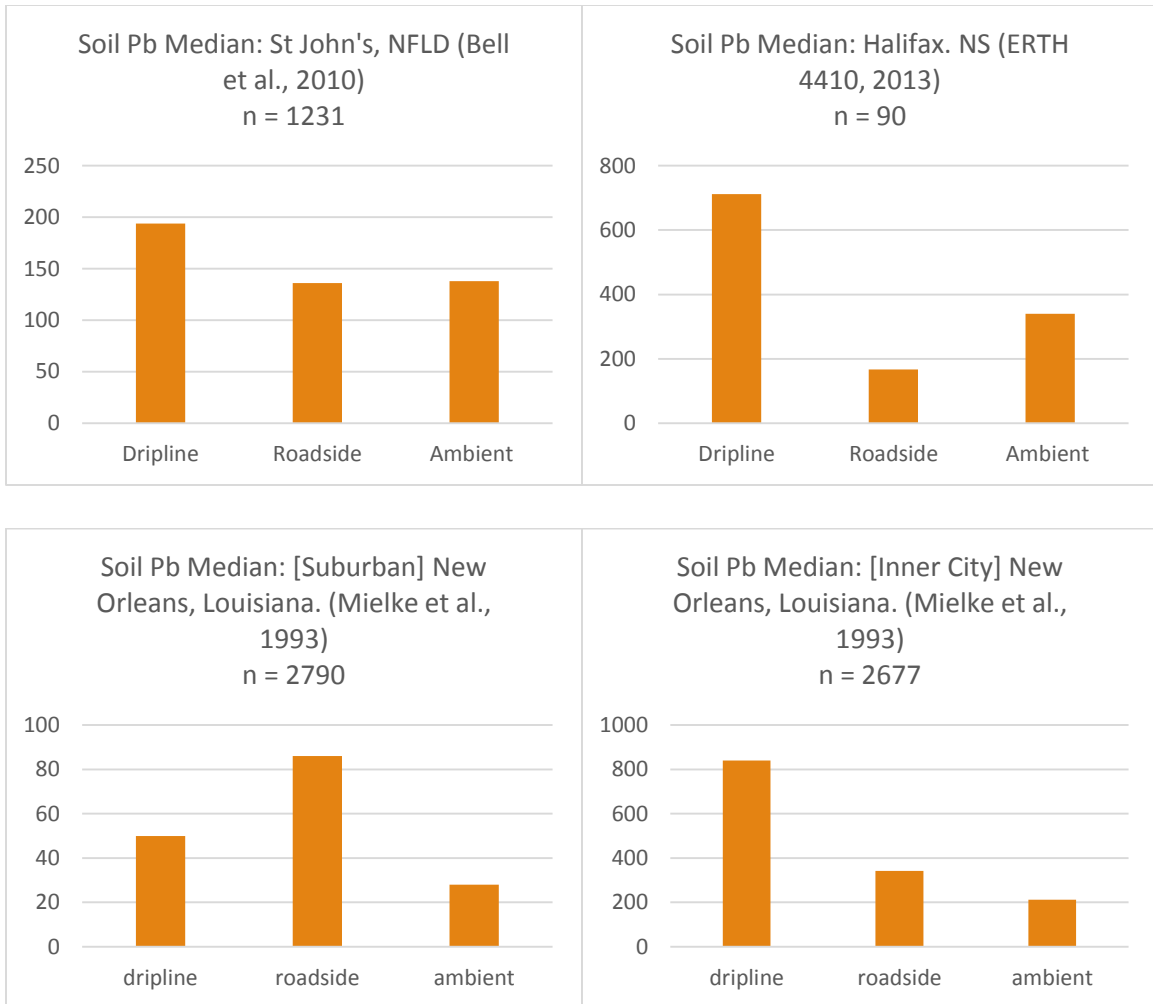


FIGURE 20: MEDIAN LEAD CONCENTRATION IN RESIDENTIAL SOILS FROM VARIOUS LOCATIONS. NOTE THAT HALIFAX AND ST JOHN'S BOTH HAVE ROADSIDE LEAD LOWER THAN AMBIENT, AND NEW ORLEANS HAS AMBIENT LOWER THAN ROADSIDE.

2.5 DE-ICING PROCEDURES IN HALIFAX, NS, CANADA

In cities such as Halifax there is a critical need for winter road maintenance, involving the use of de-icers such as salt, to ensure public safety and economic productivity. Application of salt to roads increased drastically in the 1970's, as benefits were noted. Nova Scotia is Canada's number three consumer of road salt (Environment Canada, 2001). The moderate temperatures (see Figure 21) combined with the nature of the weather events, such as freeze-thaw events, freezing rain, and wet snow increase the demand for de-icing.

The HRM has developed a salt management strategy, focusing on anti-icing (salt application prior to storm event) rather than de-icing. Anti-icing requires eight times less salt,

and is therefore a better option economically, and environmentally (Stantec, 2011). Sodium chloride is commonly used for de-icing due to its reliability and affordability, local availability, as well as easy handling, storage and application. HRM uses salt from Pugwash, NS where ferrocyanide is added as an anticaking agent. The salt is then added to sand (5%) to reduce freezing (Stantec, 2011).

The effectiveness of sodium chloride in preventing or melting ice depends on temperatures of the air and pavement as well as moisture. Sufficient heat and moisture are required to break the bond, forming a solution with sodium and chloride ions which reduces the freezing point of water, acting as a positive feedback by creating more moisture and ultimately reducing the amount of ice on the roads and keeping the snow in a state which is easier to remove mechanically (Halifax Regional Municipality, 2014). Due to the temperature requirement, sodium chloride is only effective above temperatures of -11 °C. When temperatures are too low for salt to be effective, sand or gravel are added to improve traction. In future studies it may be useful to determine the source and geochemistry of the sediment used.

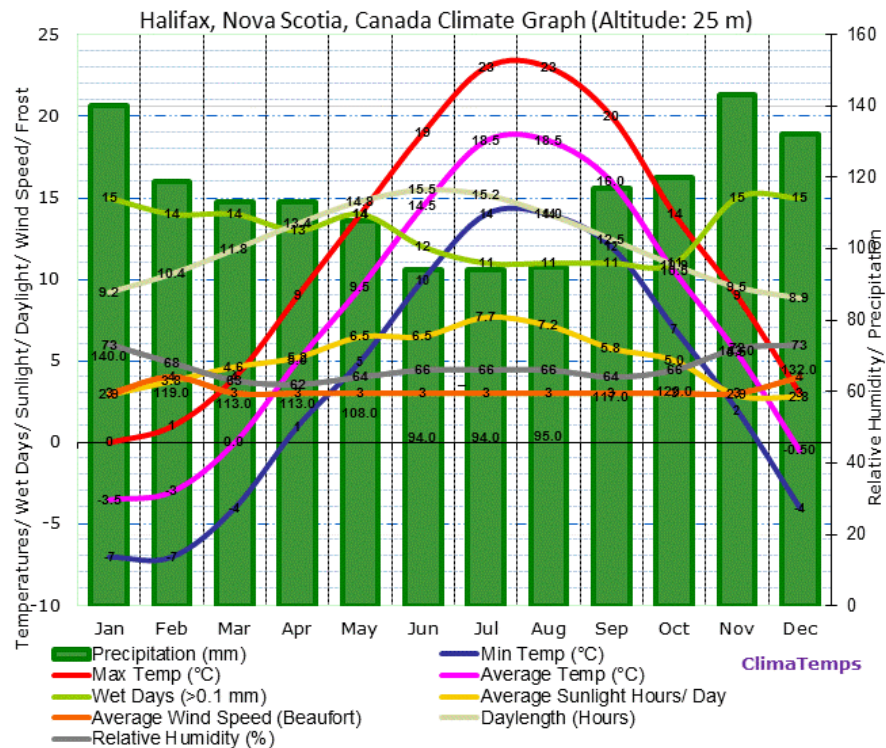


FIGURE 21: HALIFAX CLIMOGRAPH. NOTE AVERAGE MIN. TEMPERATURE >10°C, ALLOWING FOR EFFECTIVE USE OF SODIUM CHLORIDE. (CLIMATEMPS.COM, N.D.)

In addition to dry salt, the HRM employs a 23% brine solution to pre-wet dry salt. This improves the effectiveness by increasing the moisture content and facilitating the chemical process involved, as well as helping the salt stick to the road. A 23% brine solution is also sprayed directly onto the pavement before a snow or frost event to prevent ice formation (see Figure 22). The direct application practice began trial in the winter of 2012. (Halifax Regional Municipality, 2014)



FIGURE 22: HRM TRUCK APPLYING BRINE DIRECTLY TO PAVEMENT. (HALIFAX REGIONAL MUNICIPALITY, 2014)

More salt is required on the sidewalks than on the roads, because of the absence of vehicles to crush up the salt, create brine, and increase the spatial effectiveness of a salt grain (see Figure 23). The Halifax Salt Management Strategies website states that direct application of brine to sidewalks will be tested in 2014-2015.

To make better-informed decisions regarding application, infrared temperature (IRT) sensors are installed to some of the HRM's maintenance trucks to measure the pavement temperature. Furthermore, detailed weather forecasts are considered to tailor maintenance efforts to individual storms.

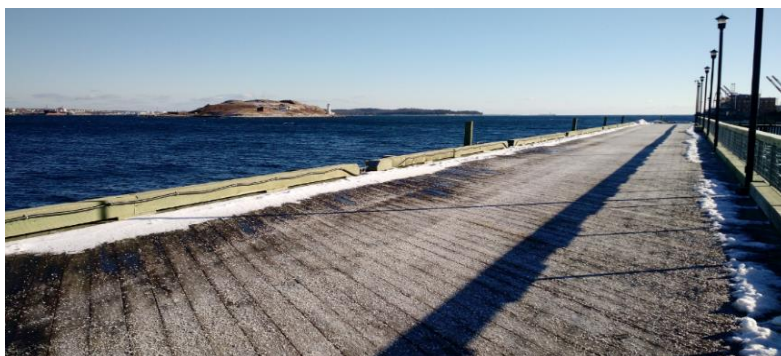


FIGURE 23: UNPLOWED HALIFAX ROAD (TOP LEFT); DE-ICING SALT ON ROAD AND WALKWAYS IN HALIFAX (LEFT); SNOW MELTING AROUND SALT GRAINS (TOP RIGHT); SALT, ICE AND ADJACENT GRASS (BOTTOM RIGHT)

2.5.1 ENVIRONMENTAL IMPACTS OF ROAD SALTS

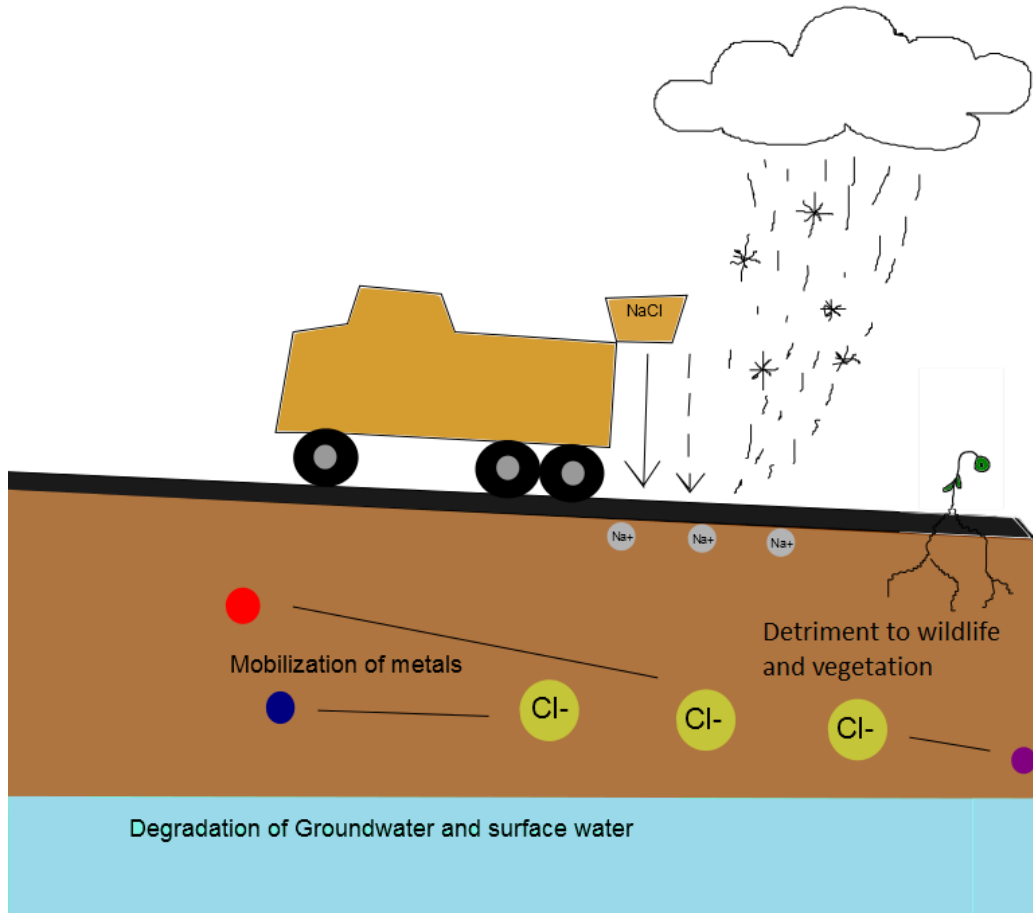


FIGURE 24: EXAMPLES OF ENVIRONMENTAL PROBLEMS ASSOCIATED WITH ROAD SALTS.

In 2011, Stantec undertook a review of best management practices regarding road salt application in the HRM. The need for de-/anti-icing practices are known, from a social and economic standpoint. As more research is done on the environmental impacts of road salt, the need for municipalities to implement better management practices for road salt application becomes clearer.

In 1995, under Canadian Environmental Protection Act (CEPA) a comprehensive scientific assessment on road salt commenced, lasting five years. It was concluded that detriment to freshwater ecosystems, soil, vegetation, and wildlife are attributable to influx of large amounts of road salt. In 2001, Environment Canada declared road salt as a toxic substance, although one not harmful to humans. CEPA introduced the Code of Practice for the Environmental Management of Road Salts in 2004, which stated that jurisdictions (such as

HRM) with vulnerable areas, or using more than 500 tonnes of road salt per year should implement best management practices. Best management practices are done to minimize environmental detriment cause by road salt, without compromising public safety or economic productivity.

Alternatives to sodium chloride are available, such as calcium chloride, potassium, chloride, and calcium magnesium acetate. All of these have their own drawbacks and sodium chloride is still favoured in the HRM due to its easy handling, effectiveness and affordability (Stantec, 2011). In some cases, the cost of material is significantly greater pound-for-pound, however the amount needed is much less, allowing for a net cost savings. This is the case with a material tested in Ottawa called EcoTraction which uses zeolite to provide traction (Stantec, 2011).

2.6 CHLORIDE LEACHING

Existing literature makes a strong case for the occurrence of chloride leaching in roadside soils. Studies such as those by Amrhein & Strong (1990), Amrhein et al. (1992, 1994), Bäckström et al (2002) have shown that de-icing salts do impact mobility of metals, through mechanisms including cation exchange, organic matter mobilization, colloid dispersion, and the formation of chloride complexes. A decrease in pH which is attributable to the addition of de-icing salts has also been noted to mobilize metals (Bäckström, 2002). Another context in which metals may be mobilized by salt is in the salinization of soils in arid/semi-arid environments (Acosta et al., 2011), although this is not relevant in a humid climate such as that of Halifax.

A small scale leaching experiment (see Figure 25) done on soil samples from the Halifax pilot study by a group of students of the Dalhousie Integrated Science Program (DISP) also supported the hypothesis that the presence of NaCl affects metals concentrations in soils. The students used controls of no salt, 8 g and 16 g salt per 100 g of soil. The soil was analyzed pre- and post-leaching using XRF. The metals of focus for this study were copper, lead, and zinc and all three had lowered concentrations with increased salinity, as demonstrated by FIGURE 26. (DISP, 2014)



FIGURE 25: DISP LEACHING EXPERIMENTS. (DISP, 2014)

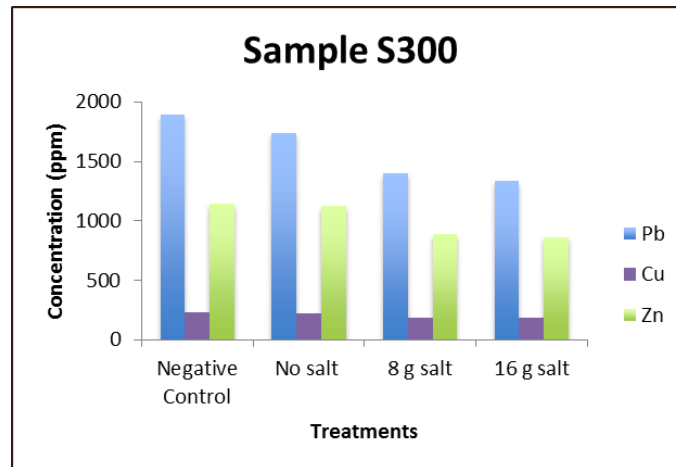


FIGURE 26: RESULTS FROM DISP STUDY. OTHER SAMPLES SHOWED SIMILAR RESULTS. (DISP, 2014)

Chapter three will discuss the methods used for the sample collection, leaching experiments, and analysis involved in this study to determine the effect of chloride on metal concentrations in soil.

2.7 SUMMARY

With considerations of the geologic and anthropogenic history discussed in this chapter, including the lithologies of the Meguma terrane found on the Halifax Peninsula, and the past and modern industrial and human history, the 2013/2014 pilot study sought to determine metal concentrations in residential soils of the Peninsula, compare them to CCME guidelines, and compare intra-site differences between ambient, dripline, and roadside samples. The study unexpectedly found roadside samples to commonly have the lowest metal concentrations, a finding which may be attributable to chloride leaching from road salts used in the winter months to ensure safety and economic productivity. Chapter three discusses the methods used to explore the interaction between soil metals and sodium chloride.

CHAPTER 3: METHODS

This chapter discusses the methods used in the execution of this study. The methodology comprises four main sections: sample collection, soil classification and sieving, leaching experiments, and quality control. An overview of the methods is shown in Figure 27.

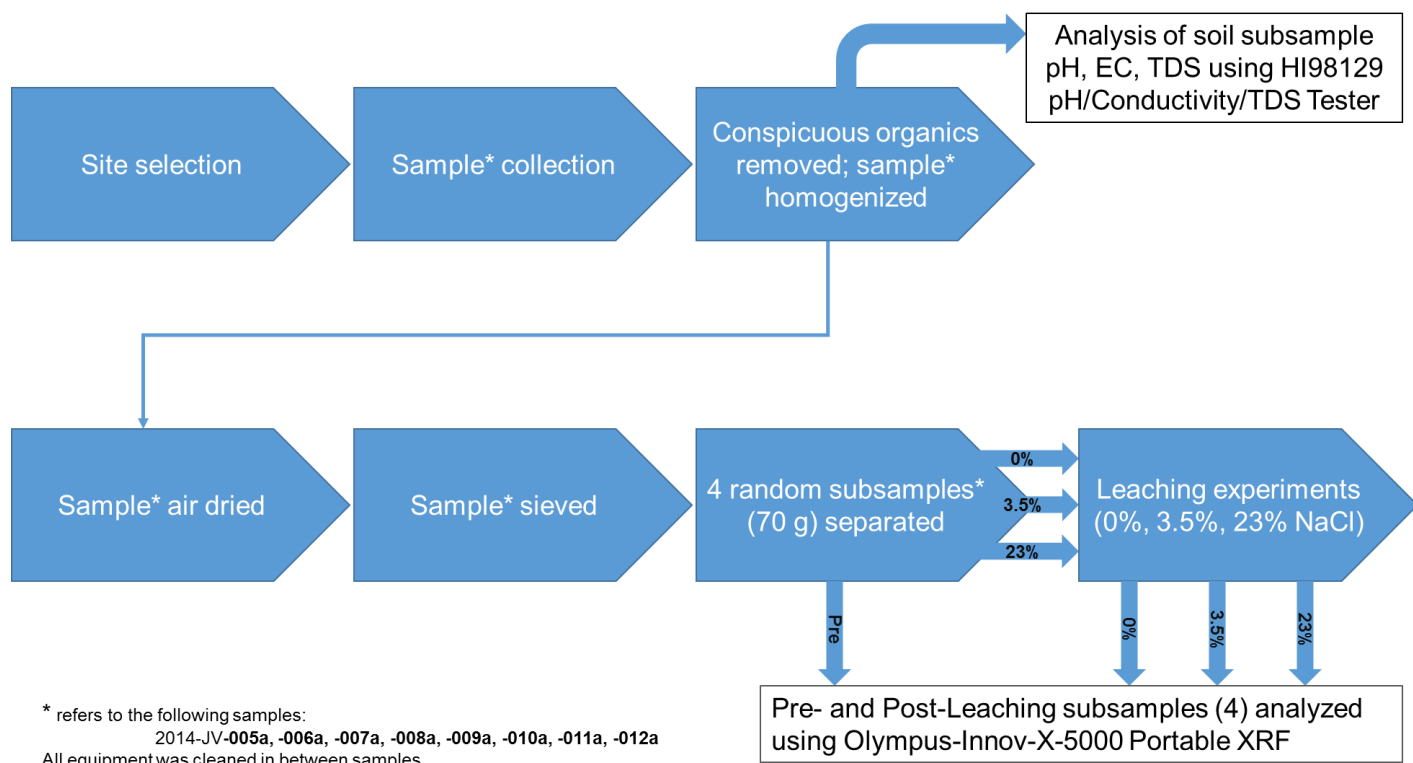


FIGURE 27: FLOWCHART OF METHODS

3.1 SAMPLING PROTOCOL

3.1.1 SAMPLE SITE & COLLECTION



FIGURE 28: SITE OF SAMPLE 005A

Sample sites were selected in areas that were deemed less likely to have been disturbed recently as evidenced by mature vegetation (see Figure 28). Areas in which construction had been done recently, or that had been recently landscaped (young trees, garden beds, etc.), were avoided. All sample locations were a minimum of one meter away from roadways or buildings. This was done with the intent of yielding a more representative baseline of the metal concentrations in the soils of the Halifax Peninsula, while better reflecting the age and history of the city. All locations were on the Sexton and Studley Campuses of Dalhousie University.

At each site, the following were recorded: time, location, station ID, slope and aspect, depth and width of hole, soil colour, soil texture (hand identification), horizon development, vegetation, land use, and any other notes that might be relevant including insect abundances (See Table 2 in chapter 4). Soil horizon development was typically absent, possibly as a result of past and recent anthropogenic disturbance.

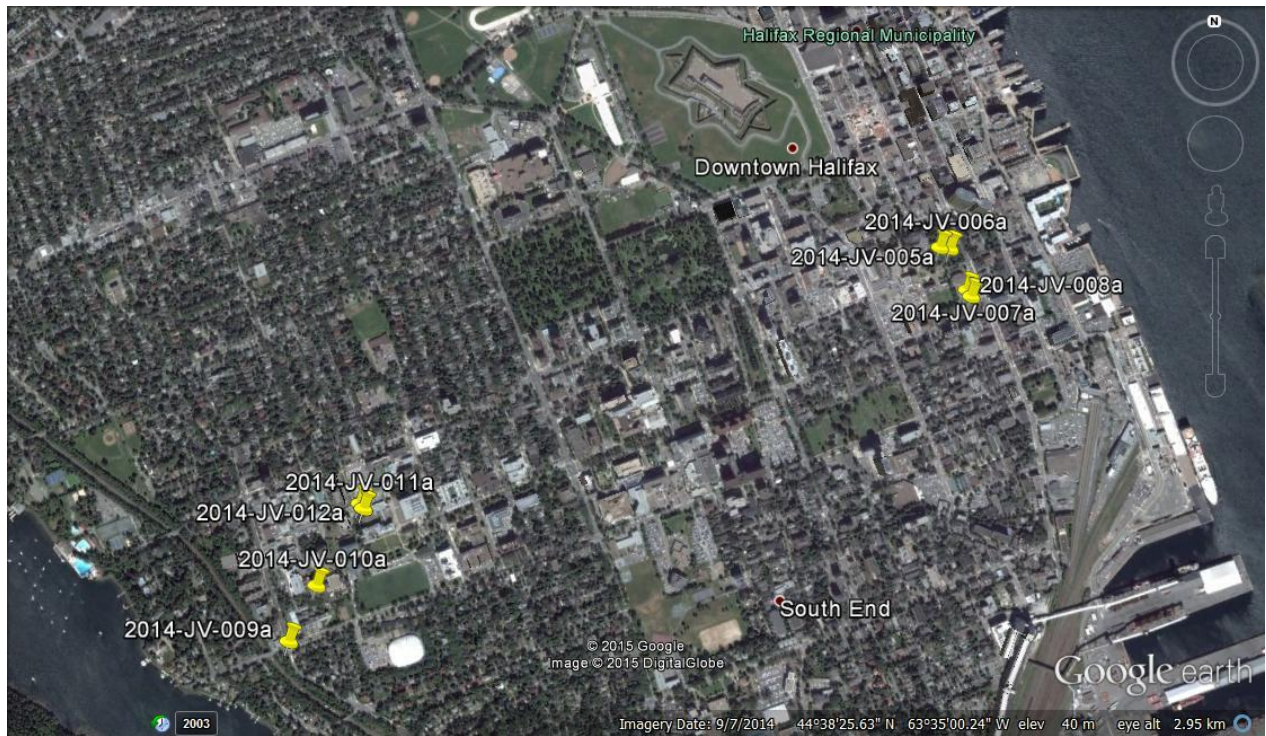


FIGURE 29: SAMPLE SITE LOCATIONS. 44°38'25.63"N 63°35'00.24"W. GOOGLE EARTH. SEPTEMBER 7, 2014. MARCH 16, 2015.

Eight soil samples were collected for the purpose of this study. The samples are identified as 2014-JV-005a, -006a, -007a, -008a, -009a, -010a, -011a, -012a. These samples are from the top 10 cm (see Figure 30), beneath the organics (O-horizon: grass, detritus). After removing the overlying organics a hole was dug using an aluminum trowel to a depth of 10 cm, with a diameter of 20 cm. Conspicuous organics and gravels were removed. The soil was placed into a food-grade storage bag, which was labeled with the station ID, depth, and date. Upon collection, soil texture was estimated by feel, using a flowchart retrieved from the website of Colorado State University Extension (Whiting et al., 2014). Site and sample characteristics were recorded and potting soil was used to fill the holes before replacing the organic cover



FIGURE 30: SITES OF -005A (TOP LEFT), -006A (TOP*/BOTTOM RIGHT), -011A (BOTTOM LEFT).
*NOTE RED OXIDIZED AREAS.

3.2 SOIL CLASSIFICATION AND SIEVING

3.2.1 SIEVING

The soils were laid out on clean, unbleached paper to air dry at room temperature for five days (see Figure 31), and then returned to their respective storage bags. When dry, the entire sample was sieved to separate the <2 mm fraction. Textural classification was done in the field by hand identification.



FIGURE 31: SOIL SAMPLES AIR-DRYING.

3.2.2 ELECTRICAL CONDUCTIVITY, TOTAL DISSOLVED SOLIDS, AND PH

Homogenized soil subsamples were mixed with distilled water at a 1:2 ratio by volume, stirred vigorously for approximately one minute with a plastic stir stick (new stick for each sample) and left for 30 minutes (See Figure 32). Electrical conductance (EC), total dissolved solids (TDS), pH and temperature were measured using a “HI98129 pH/Conductivity/TDS Tester” with accuracies of +/-0.05 for pH, 2% for conductivity and total dissolved solids, and +/- 0.5^oC for temperature (see Table 2 in chapter 4). Buffer solutions of pH 4.01 and 6.86 were used to confirm the accuracy of the probe, which was rinsed with distilled water between each sample to minimize the risk of contamination.

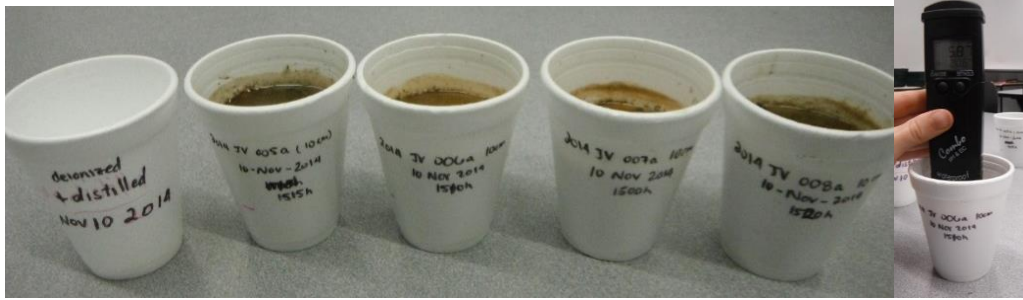


FIGURE 32: SOIL SOLUTION (2:1 DI WATER: SOIL) ANALYZED FOR EC, TDS, AND PH.

3.3 SOIL FILTRATION EXPERIMENT

3.3.1 XRF ANALYSIS OF INITIAL METALS

Subsamples of the <2 mm fraction of each sample were set aside to be analyzed using X-ray fluorescence (XRF) for metal concentrations, as a baseline to which the metal concentrations in the salt-treated soils could be compared. XRF analysis was done using an Olympus-Innov-X-5000 Portable XRF.

3.3.2 EXPERIMENT DESIGN

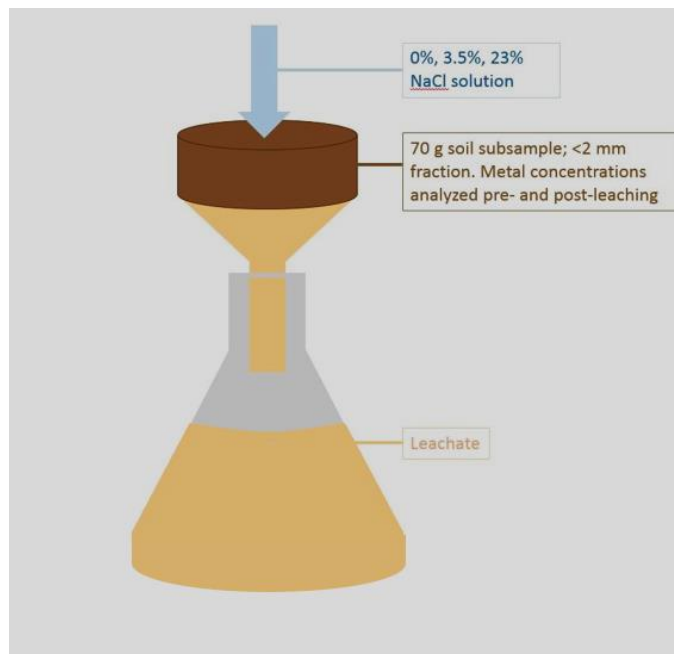


FIGURE 33: SCHEMATIC DIAGRAM OF FILTRATION EXPERIMENT

The leaching experiment utilized six 165 mL Buchner funnels with diameter of 3.5 cm, lined with a no. 1 Whatmann filter paper. The lined funnels rested in a 1 L Erlenmeyer flask into which the associated leachate drained (See Figure 33). In each of the six funnels, a 70 g subsample of homogenized soil was leveled gently with the base of a clean beaker to a depth of approximately 1 cm, as the soil samples were from the top 10 cm and experiments were scaled down by a factor of 10.

Soil was dried and analyzed using XRF for post-leaching metal concentrations. Any difference in pre- and post-leaching metal concentrations, comparisons and contrasts between the behaviour various metals with CCME guidelines, as well as differences as a function of the varying salinity of the solutions used was be noted, and are discussed in chapter 5.

3.3.3 SALINE SOLUTIONS

Ten soil samples were utilized for the experiments, each was leached with three solutions of varying salinity: 0%, 3.5%, and 23% NaCl. The 0% is distilled water, the 3.5% is to approximate seawater, and the 23% is to represent the liquid brine (23% salt solution) that is used in the pre-wetting procedure by the municipality as an anti-icing strategy (Stantec, 2011; Halifax Regional Municipality, 2014) The solutions were made by dissolving 230 g and 35 g of SIFTO® SAFE STEP® ICE SALT™ (sodium chloride (Sifto, 2011)) in one liter of distilled water for the 23% and 3.5% solutions, respectively. A better representation of precipitation may have been to acidify the solutions slightly. However, with the variability in the chemistry of the precipitation over Halifax, based on where the system comes from, this is difficult to emulate and therefore distilled water was used. Also the introduction of an acid may make it harder to attribute mobilization to chloride from the salts.

The quantity of solution applied sought to reflect the average annual precipitation of Halifax over an area of 7 cm², scaled-down by a factor of ten to agree with the scaling down of the soil depth from 10 cm to 1 cm. All ten soils had one year's worth of solution added, and some were repeated for an equivalent of two years.

3.4 QUALITY ASSURANCE/ QUALITY CONTROL

Several efforts were made to ensure the quality of this study. Throughout the whole process, from sampling to the filtration experiment, care was taken and considerations made to minimize contamination. During the sampling process, bags were clearly labeled, field notes were carefully made, and aluminum trowels were used and cleaned with distilled water in between samples. Aluminum trowels were selected over other materials, such as stainless steel, because this study will only be focusing on metals which have CCME guidelines. There is no CCME guideline for aluminum, nor is it detectable by XRF, making it a suitable choice. Stainless steel can have 12-30% chromium, commonly 18% Cr and 8% Ni. (Chemistry Explained, n.d), Chromium has a CCME guideline of 64 ppm for agricultural and residential soils, and 87 ppm for commercial and industrial soils. Using stainless steel may run the risk of contamination, compromising the quality of the data. The bags used for sample storage were food-grade storage bags made from 99-100% polyethylene (Clorox, 1999) which are unlikely to cause contamination.

For the analyses of EC, TDS, and pH the meter was tested for accuracy in buffer solutions and rinsed with distilled and deionized water between buffers and between samples. With respect to the XRF analyses, quality was ensured by analyzing at least one duplicate for every sample, for both the pre-and post-leaching metal concentrations of the soils. This was to minimize the risk of inhomogeneity or “noise” in the analysis from the higher sodium concentrations. The duplicate results were averaged for each sample. The road salt was also analyzed using XRF and metal concentrations of the salt were considered with the results.

CHAPTER 4: RESULTS

4.1 SUMMARY OF FIELD RESULTS

The soil samples collected for this study ranged in colours from near-black to reddish brown, with 38% of them being described in the field as “medium brown”. Sandy loam was the dominant texture identified in the field. All samples were taken from “green space” areas with grass and deciduous trees. All field information is in Table 8.

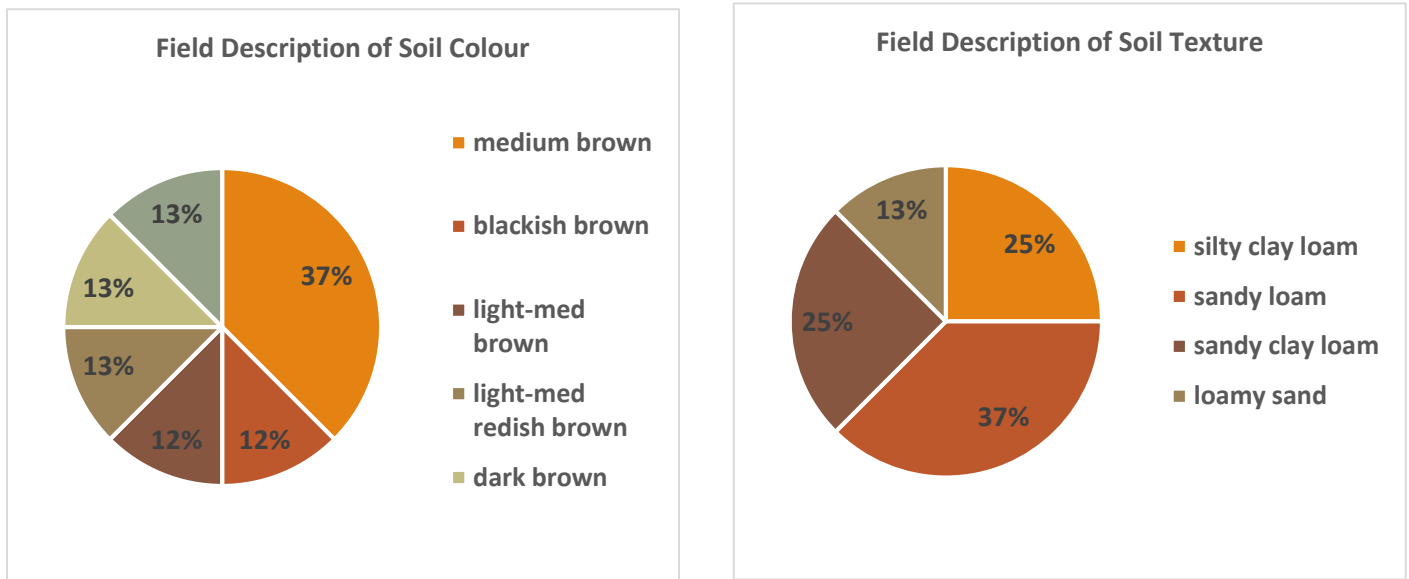


FIGURE 34: FIELD DESCRIPTION OF SOIL COLOUR AND TEXTURE.

At a mean temperature of 20.1 +/- 0.5°C, the eight soil samples collected for this study have pH values ranging from 5.67 to 6.74 +/-0.05, TDS values from 3 ppm to 18.5 ppm +/- 1ppm, and EC values from 6 to 37 +/-2% f.s.. (See Table 2)

TABLE 2: SELECT SOIL PROPERTIES. ANALYZED USING “HI98129 PH/CONDUCTIVITY/TDS TESTER” WITH ACCURACIES OF +/-0.05 FOR PH, 2% FOR CONDUCTIVITY AND TOTAL DISSOLVED SOLIDS, AND +/-0.5°C FOR TEMPERATURE

Station ID	Temp (°C)	pH	TDS (ppm)	EC (µs)
2014-JV-005a	20.7	6.02	3	6
2014-JV-006a	20.6	5.87	6	13.5
2014-JV-007a	20.5	6.45	18.5	37
2014-JV-008a	20.8	6.12	6	12
2014-JV-009a	19.7	5.67	6	12
2014-JV-010a	19.6	6.53	4	8
2014-JV-011a	19.8	6.69	5	10
2014-JV-012a	19.6	6.74	6	12
min	19.6	5.67	3	6
max	20.8	6.74	18.5	37
mean	20.1625	6.26125	6.8125	13.8125
st.dev.	0.4973367	0.37109	4.5410454	9.06207

4.2 LEACHING EXPERIMENTS

Due to instrument (XRF) repairs, the study included four phases. The first phase involved analyses of two soil suites by XRF at Saint Mary’s University using a Phillips PW2400 spectrometer, to provide preliminary data to test the basic premise while waiting for repairs to the portable XRF. The two suites are identified as 006a* and 009a*. The second phase involved analysis of all soil suites collected and leached for the equivalent of one year, using the portable XRF. The third phase involved analysis of select soil suites following leaching for the equivalent of two years. The fourth phase involved leaching of two samples (PS1& PS2) collected in Fall 2013 with known elevated levels of many metals for an equivalent of one year, and analysis thereof. Phase 2, 3 and 4 analyses were done using an Olympus-Innov-X-5000 Portable XRF.

4.2.1 CONCENTRATIONS OF SELECT METALS

PS1 and PS2 refer to two samples from the initial pilot study with known elevated metal concentrations, which were subjected to leaching experiments in this study.

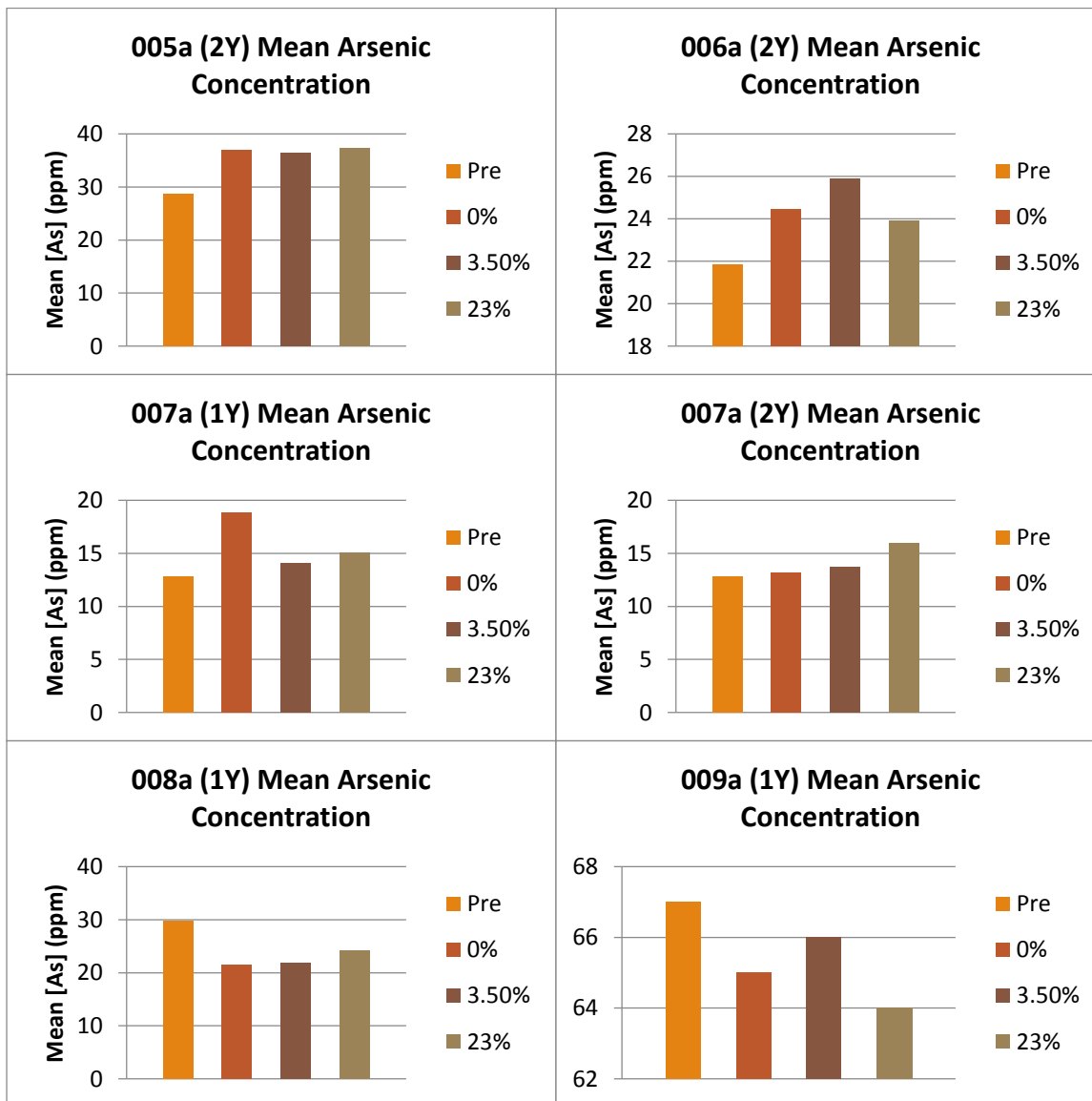
ARSENIC

No consistent trends were observed for arsenic. (See Figure 35). The apparent changes in concentration are typically within the standard deviation calculated using Microsoft Excel software. (See Table 3).

PHASE ONE ANALYSIS

Arsenic was not analyzed in the soil suites for phase one.

PHASE TWO – FOUR ANALYSIS



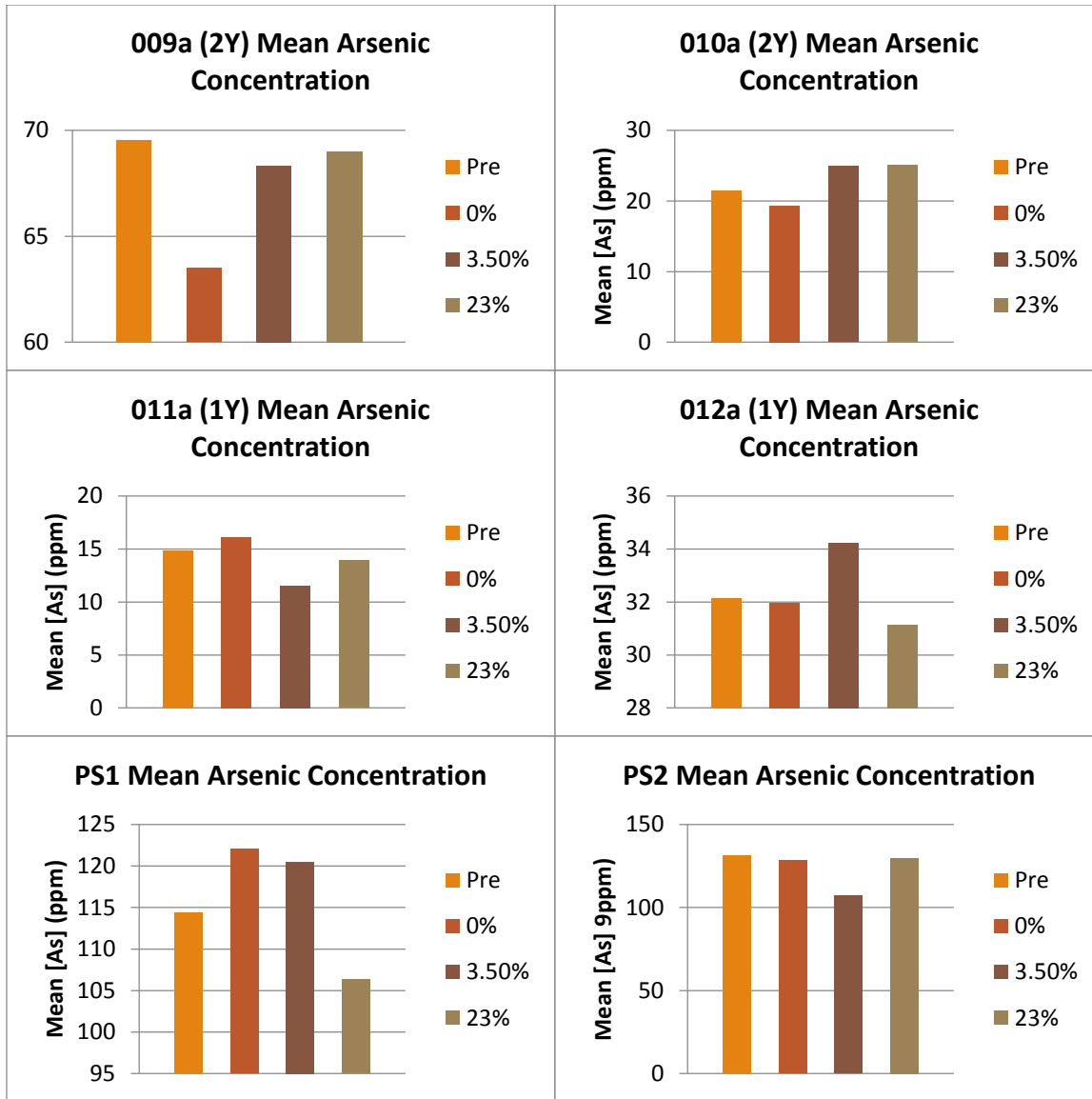


FIGURE 35: MEAN ARSENIC CONCENTRATIONS FOR PHASE TWO - FOUR SOIL SUITES. STANDARD DEVIATION AND N VALUES IN TABLE BELOW.

TABLE 3: ARSENIC MEAN CONCENTRATION, STANDARD DEVIATION, AND NUMBER OF DUPLICATES FOR PHASE TWO – FOUR SOIL SUITES.

Sample no.	Control	Years	Mean [As] (ppm)	St.Dev.	n
005a.1	Pre		28.7	2.1	2
005a.2	0	2	37.0	1.4	2
005a.1	3.5	2	36.4	6.1	5
005a.1	23	2	37.3	2.4	4
006a.1	Pre		21.8	1.6	4
006a.1	0	2	24.5	2.6	5
006a.1	3.5	2	25.9	1.2	5
006a.1	23	2	23.9	2.5	4
007a	P		12.8	1.5	3
007a.1	0	1	18.8	1.7	2
007a.1	3.5	1	14.1	0.6	2
007a.1	23	1	15.1	1.9	2
007a	P		12.8	1.5	3
007a.2	0	2	13.2	0.9	2
007a.2	3.5	2	13.7	1.6	2
007a.2	23	2	16.0	1.8	2
008a.1	Pre		29.8	13.1	2
008a.1	0	1	21.6	0.1	2
008a.1	3.5	1	22.0	1.3	2
008a.1	23	1	24.2	0.5	2
009a.1	Pre		67.0	1.4	4
009a.1	0	1	65.0	2.8	2
009a.1	3.5	1	66.0	14.1	2
009a.1	23	1	64.0	4.0	3
009a.3	Pre		69.5	0.7	2
009a.3	0	2	63.5	3.5	2
009a.3	3.5	2	68.3	6.4	3
009a.3	23	2	69.0	5.7	2
010a.1	Pre		21.5	1.9	2
010a.1	0	1	19.3	0.1	2
010a.1	3.5	1	24.9	3.5	2
010a.1	23	1	25.0	5.7	5
011a.1	Pre		14.9	1.1	2
011a.1	0	1	16.1	1.4	2
011a.1	3.5	1	11.6	1.2	2
011a.1	23	1	13.9	0.8	2
012a.1	Pre		32.2	2.0	4
012a.1	0	1	32.0	2.4	6
012a.1	3.5	1	34.2	1.9	5
012a.1	23	1	31.2	1.6	6
PS1	Pre		114.3	16.3	3
PS1	0	1	122.0	9.5	3
PS1	3.5	1	120.5	7.8	2
PS1	23	1	106.3	4.2	3
PS2	Pre		131.0	11.3	2
PS2	0	1	128.5	18.9	3
PS2	3.5	1	107.0	8.5	3
PS2	23	1	129.7	10.2	3
NaCl			<LOD		

COPPER

No consistent trends were observed for copper, and changes in concentration are typically within standard deviation. The road salt used for the study was analyzed and has a mean concentration of 12.5 ppm Cu, with a standard deviation of 2.5 ppm. This could account for some of the apparent changes and ranges in concentration.

PHASE ONE ANALYSIS

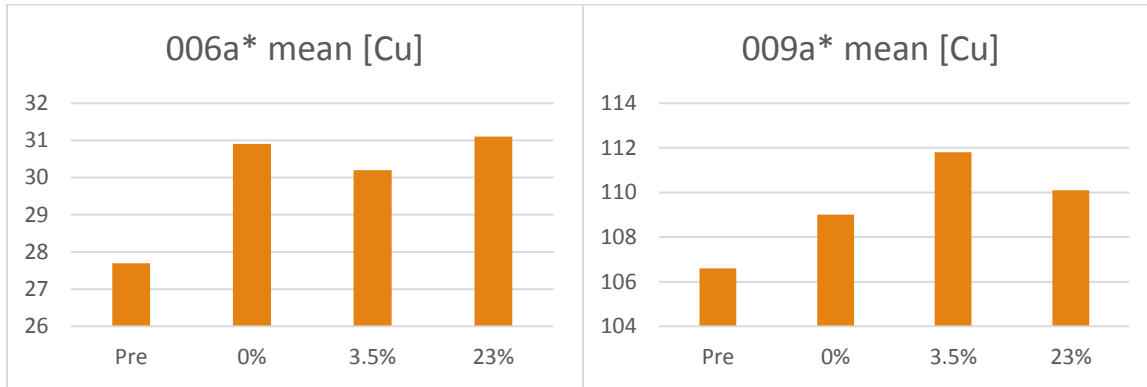
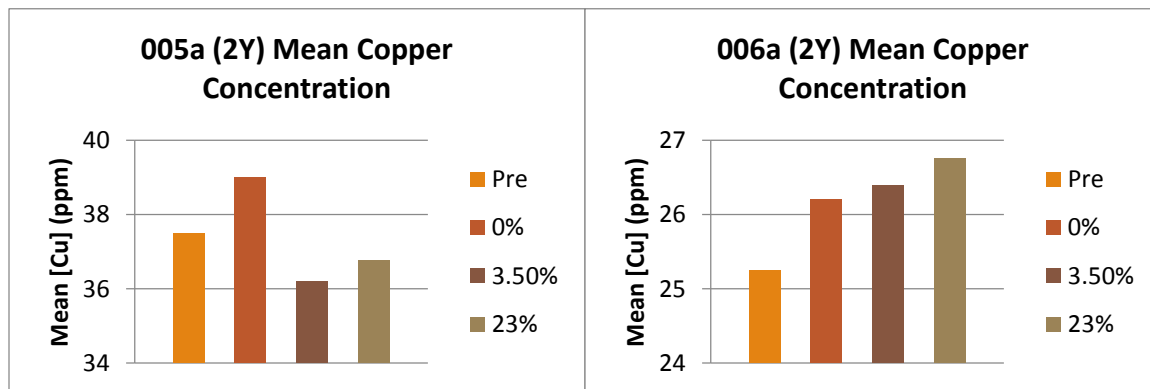
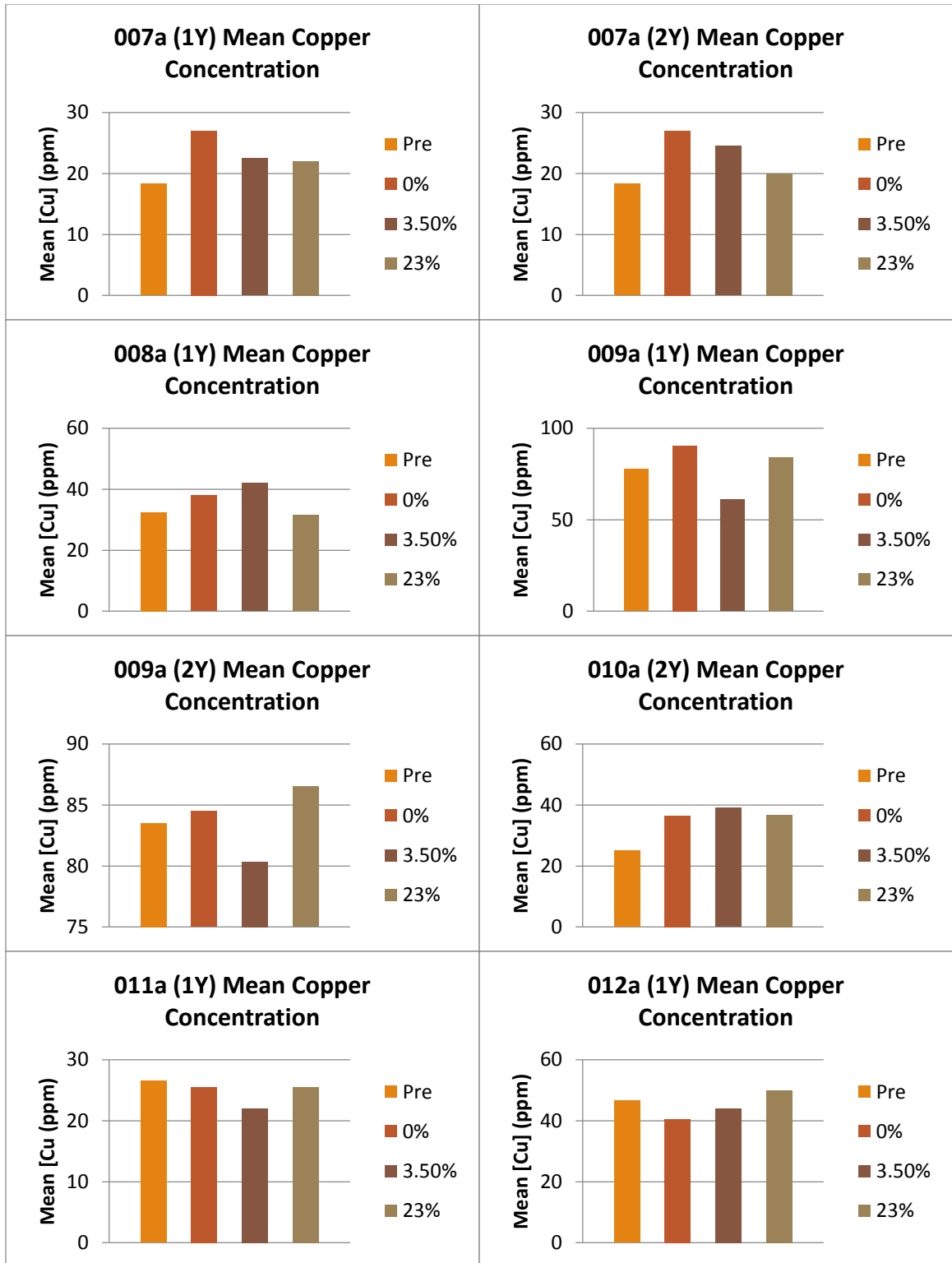


FIGURE 36: MEAN COPPER CONCENTRATIONS OF PHASE ONE SOIL SUITES.

PHASE TWO – FOUR ANALYSIS





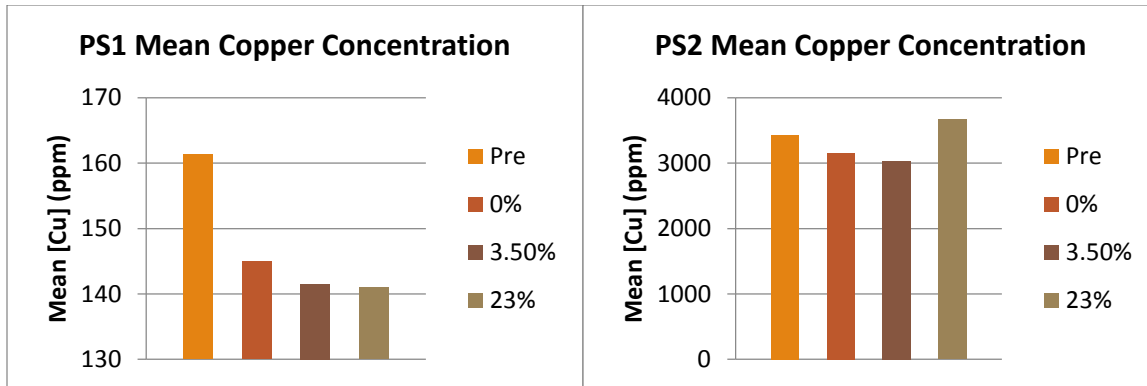


FIGURE 37: MEAN COPPER CONCENTRATIONS OF PHASE TWO - FOUR SOIL SUITES. STANDARD DEVIATION AND NUMBER OF DUPLICATES (N) LISTED IN TABLE BELOW

TABLE 4: MEAN COPPER CONCENTRATION, STANDARD DEVIATION, AND NUMBER OF DUPLICATES FOR PHASE TWO - FOUR SOIL SUITES.

Sample no.	Control	Years	Mean [Cu] (ppm)	St.Dev.	N
005a.1	Pre	2	37.5	2.1	2
005a.2	0	2	39.0	1.4	2
005a.1	3.5	2	36.2	5.5	5
005a.1	23	2	36.8	2.6	4
006a.1	Pre	2	25.3	3.8	4
006a.1	0		26.2	2.9	5
006a.1	3.5	2	26.4	3.0	5
006a.1	23	2	26.8	2.9	4
007a	P	1	18.3	2.1	3
007a.1	0	1	27.0	1.4	2
007a.1	3.5	1	22.5	0.7	2
007a.1	23	1	22.0	4.2	2
007a	P	2	18.3	2.1	3
007a.2	0	2	27.0	1.4	2
007a.2	3.5	2	24.5	4.9	2
007a.2	23	2	20.0	2.8	2
008a.1	Pre	1	32.5	0.7	2
008a.1	0	1	38.0	0.0	2
008a.1	3.5	1	42.0	1.4	2
008a.1	23	1	31.5	0.7	2
009a.1	Pre	1	77.5	4.9	4
009a.1	0	1	90.5	30.4	2
009a.1	3.5	1	61.0	5.7	2
009a.1	23	1	84.0	4.4	3
009a.3	Pre	2	83.5	3.5	2
009a.3	0	2	84.5	6.4	2
009a.3	3.5	2	80.3	3.8	3
009a.3	23	2	86.5	4.9	2
010a.1	Pre	1	25.0	4.2	2
010a.1	0	1	36.5	2.1	2
010a.1	3.5	1	39.0	4.2	2
010a.1	23	1	36.8	3.3	5
011a.1	Pre	1	26.5	4.9	2
011a.1	0	1	25.5	0.7	2
011a.1	3.5	1	22.0	2.8	2
011a.1	23	1	25.5	2.1	2
012a.1	Pre	1	46.5	1.7	4
012a.1	0	1	40.5	1.4	6
012a.1	3.5	1	44.0	4.7	5
012a.1	23	1	50.0	22.3	6
PS1	Pre	1	161.3	4.5	3
PS1	0	1	145.0	8.5	3
PS1	3.5	1	141.5	4.9	2
PS1	23	1	141.0	4.6	3
PS2	Pre	1	3430.5	433.5	2
PS2	0	1	3155.8	176.2	3
PS2	3.5	1	3036.0	60.7	3
PS2	23	1	3665.3	306.1	3
NaCl			12.5	2.5	4

LEAD

For lead, samples with high initial concentrations (PS1 and PS2) show decrease in concentration with increased salinity. Analysis of the road salt shows only 4 ppm lead.

PHASE ONE ANALYSIS

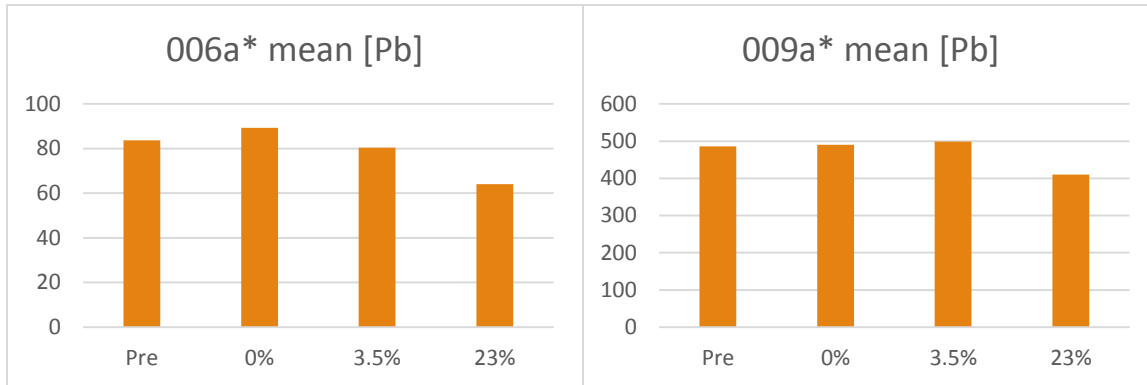
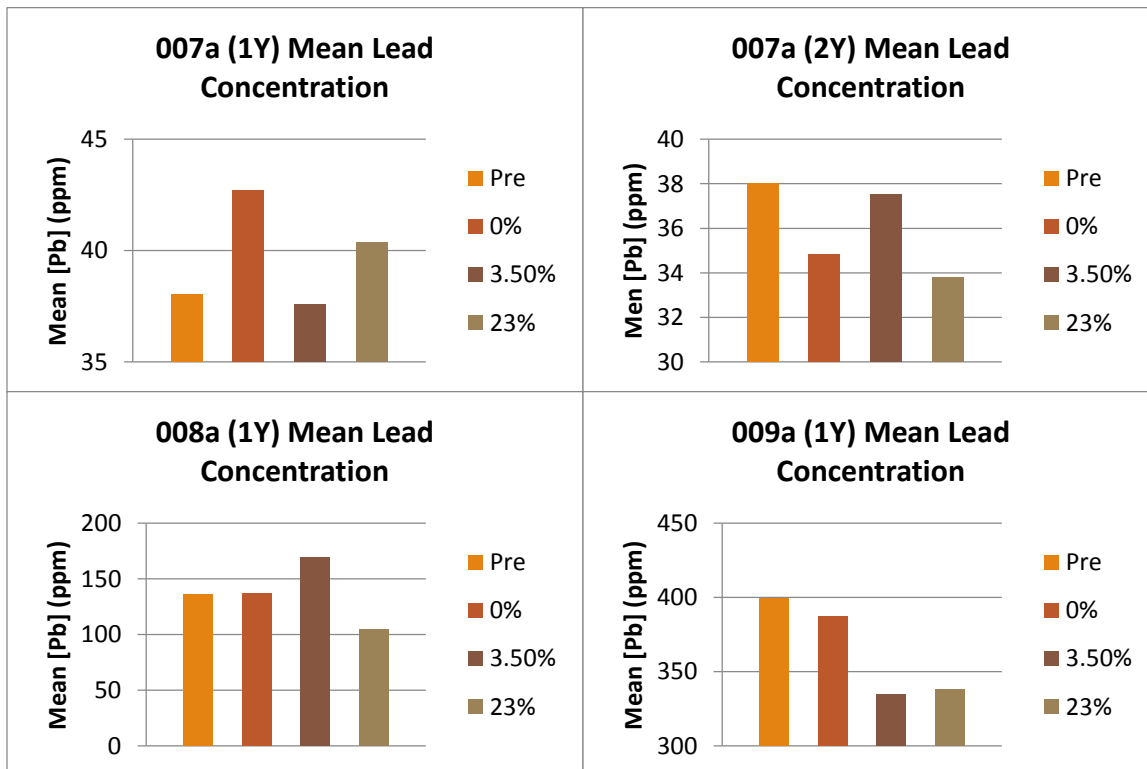


FIGURE 38: MEAN LEAD CONCENTRATION OF PHASE ONE SOIL SUITES.

PHASE TWO – FOUR ANALYSIS



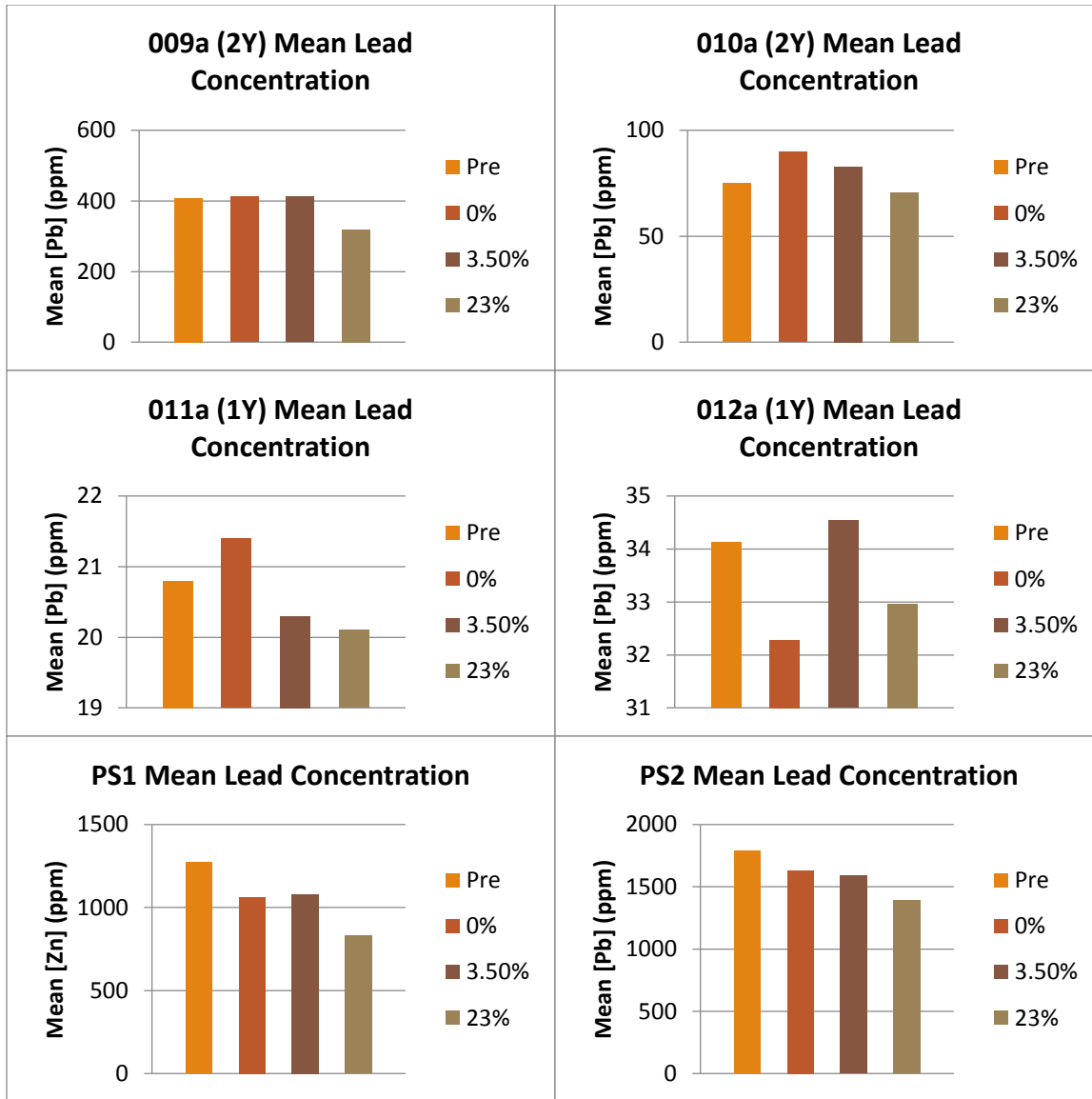


FIGURE 39: MEAN LEAD CONCENTRATION OF PHASE TWO - FOUR SOIL SUITES. STANDARD DEVIATION AND NUMBER OF DUPLICATES (N) LISTED IN TABLE BELOW.

TABLE 5: MEAN LEAD CONCENTRATION, STANDARD DEVIATION, AND NUMBER OF DUPLICATES FOR PHASE TWO - FOUR SOIL SUITES.

Sample no.	Control	Years	Mean [Pb] (ppm)	St.Dev.	N
005a.1	Pre	2	157.0	2.8	2
005a.2	0	2	163.5	2.1	2
005a.1	3.5	2	167.4	12.0	5
005a.1	23	2	116.3	7.4	4
006a.1	Pre	2	67.0	6.4	4
006a.1	0		69.7	8.8	5
006a.1	3.5	2	74.0	5.4	5
006a.1	23	2	52.1	3.4	4
007a	P	1	38.0	3.6	3
007a.1	0	1	42.7	3.8	2
007a.1	3.5	1	37.6	1.4	2
007a.1	23	1	40.4	0.6	2
007a	P	2	38.0	3.6	3
007a.2	0	2	34.9	0.4	2
007a.2	3.5	2	37.5	0.7	2
007a.2	23	2	33.8	2.0	2
008a.1	Pre	1	136.5	13.4	2
008a.1	0	1	137.0	1.4	2
008a.1	3.5	1	169.5	43.1	2
008a.1	23	1	104.5	6.4	2
009a.1	Pre	1	399.5	6.2	4
009a.1	0	1	387.5	6.4	2
009a.1	3.5	1	335.0	1.4	2
009a.1	23	1	338.3	8.7	3
009a.3	Pre	2	407.5	27.6	2
009a.3	0	2	412.5	9.2	2
009a.3	3.5	2	413.0	4.0	3
009a.3	23	2	319.5	12.0	2
010a.1	Pre	1	75.0	13.5	2
010a.1	0	1	89.9	0.4	2
010a.1	3.5	1	82.9	4.0	2
010a.1	23	1	70.8	10.2	5
011a.1	Pre	1	20.8	1.7	2
011a.1	0	1	21.4	1.8	2
011a.1	3.5	1	20.3	0.4	2
011a.1	23	1	20.1	0.4	2
012a.1	Pre	1	34.1	1.4	4
012a.1	0	1	32.3	3.0	6
012a.1	3.5	1	34.5	2.6	5
012a.1	23	1	33.0	4.4	6
PS1	Pre	1	1271.7	61.8	3
PS1	0	1	1063.3	42.4	3
PS1	3.5	1	1079.5	0.7	2
PS1	23	1	829.7	12.4	3
PS2	Pre	1	1786.5	82.7	2
PS2	0	1	1633.0	37.0	3
PS2	3.5	1	1590.0	27.5	3
PS2	23	1	1391.3	46.5	3
NaCl			4.0	0.0	1

ZINC

For zinc, similar trends as with lead can be noted. Samples with high initial concentrations (PS1 and PS2) exhibit a consistent decrease in concentration with increased salinity. This is likely due to the proportion of labile metal in the sample.

PHASE ONE ANALYSIS

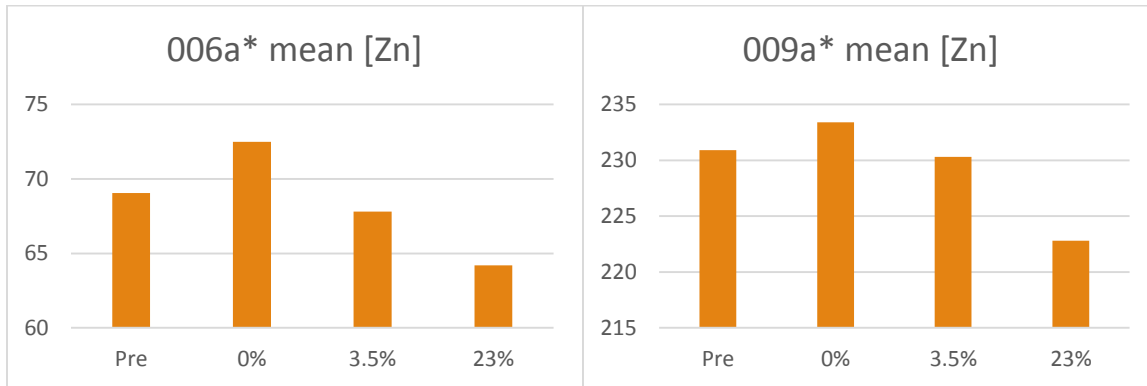
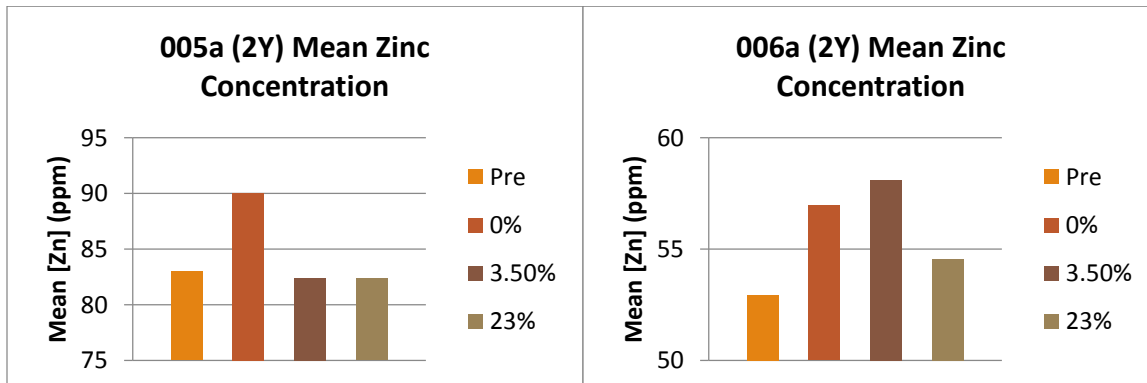
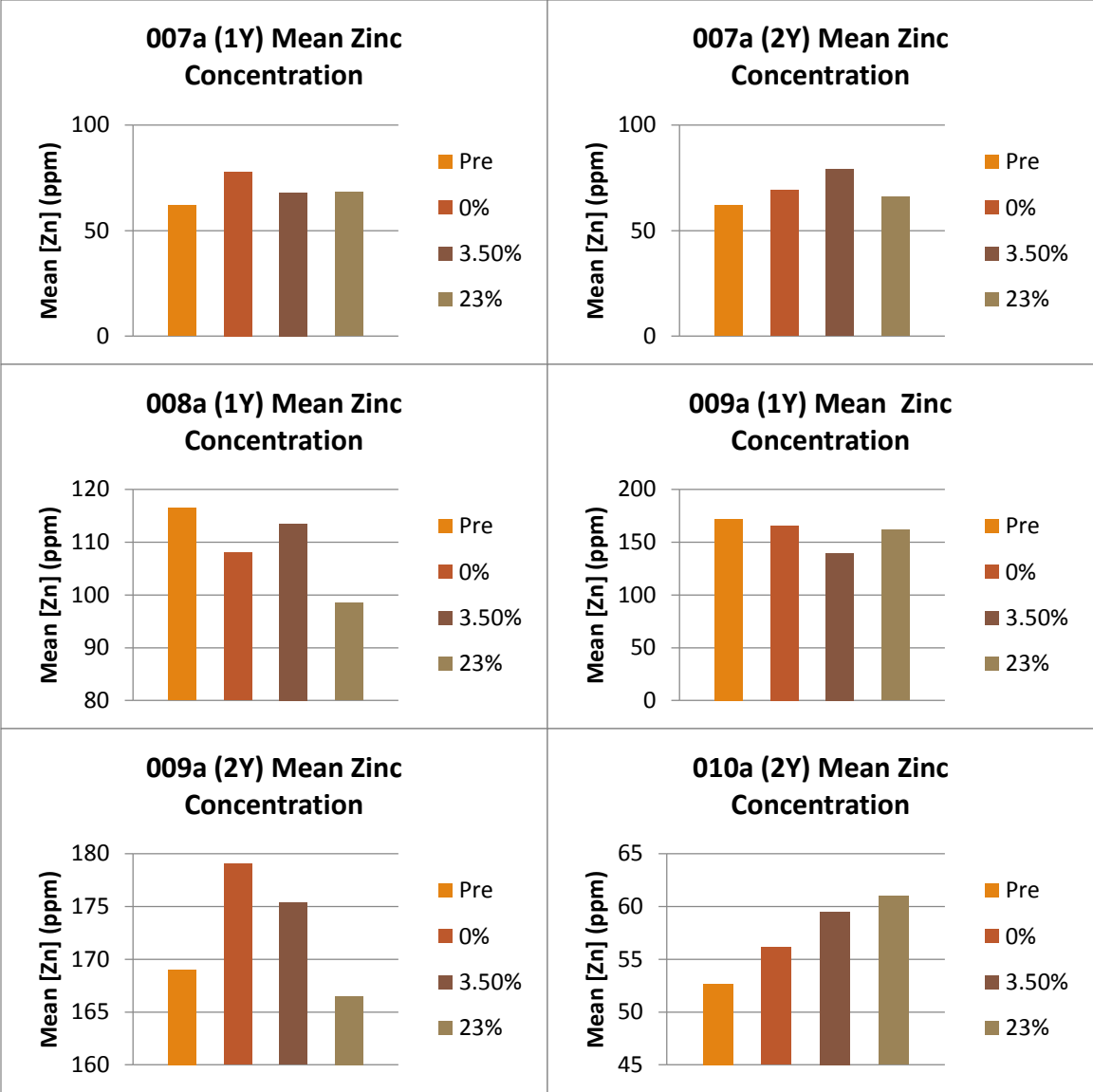


FIGURE 40: MEAN ZINC CONCENTRATION OF PHASE ONE SOIL SUITES.

PHASE TWO – FOUR ANALYSIS





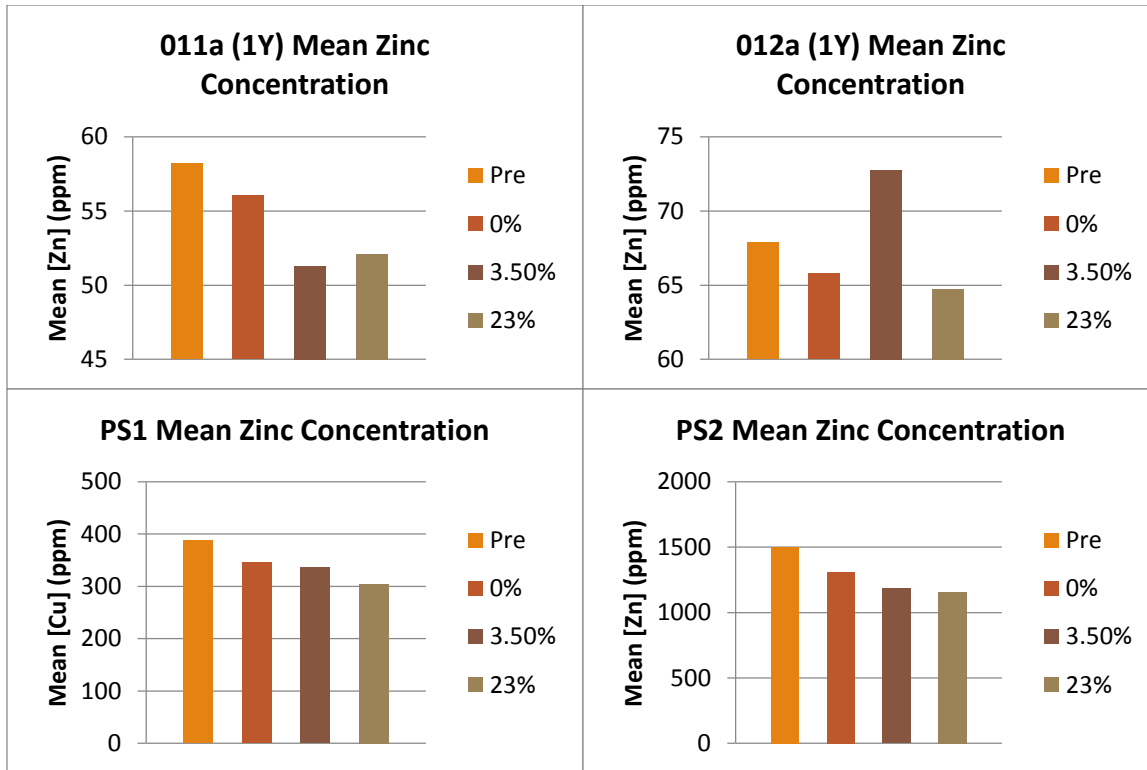


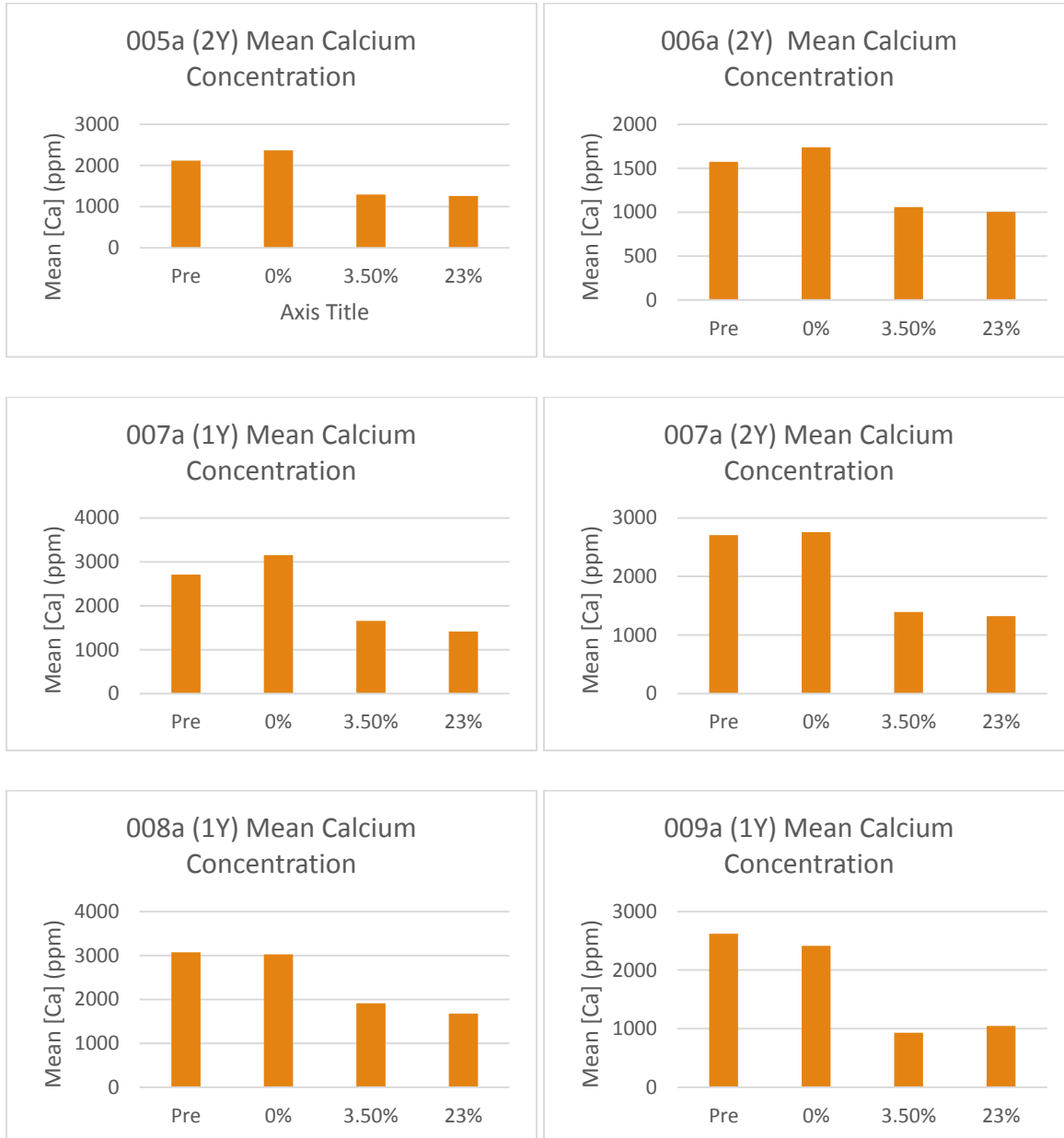
FIGURE 41: MEAN ZINC CONCENTRATIONS OF PHASE TWO - FOUR SOIL SUITES. STANDARD DEVIATION AND NUMBER OF DUPLICATES GIVEN IN TABLE BELOW

TABLE 6: MEAN ZINC CONCENTRATIONS, STANDARD DEVIATION, AND NUMBER OF DUPLICATES FOR PHASE TWO - FOUR SOIL SUITES.

Sample no.	Control	Years	Mean [Zn] (ppm)	St.Dev.	N
005a.1	Pre	2	83.0	1.4	2
005a.2	0	2	90.0	2.8	2
005a.1	3.5	2	82.4	9.3	5
005a.1	23	2	82.4	3.4	4
006a.1	Pre	2	53.0	2.4	4
006a.1	0		57.0	4.8	5
006a.1	3.5	2	58.1	1.8	5
006a.1	23	2	54.6	3.0	4
007a	P	1	62.0	3.5	3
007a.1	0	1	77.9	4.4	2
007a.1	3.5	1	67.9	2.4	2
007a.1	23	1	68.3	4.2	2
007a	P	2	62.0	3.5	3
007a.2	0	2	69.0	1.4	2
007a.2	3.5	2	79.0	1.4	2
007a.2	23	2	66.0	0.0	2
008a.1	Pre	1	116.5	19.1	2
008a.1	0	1	108.0	1.4	2
008a.1	3.5	1	113.5	9.2	2
008a.1	23	1	98.5	2.1	2
009a.1	Pre	1	171.8	2.2	4
009a.1	0	1	165.5	4.9	2
009a.1	3.5	1	139.5	3.5	2
009a.1	23	1	161.3	7.6	3
009a.3	Pre	2	169.0	1.4	2
009a.3	0	2	179.0	4.2	2
009a.3	3.5	2	175.3	9.9	3
009a.3	23	2	166.5	3.5	2
010a.1	Pre	1	52.7	5.4	2
010a.1	0	1	56.1	1.3	2
010a.1	3.5	1	59.5	2.0	2
010a.1	23	1	61.0	9.3	5
011a.1	Pre	1	58.2	1.1	2
011a.1	0	1	56.1	4.3	2
011a.1	3.5	1	51.3	0.8	2
011a.1	23	1	52.1	3.0	2
012a.1	Pre	1	67.9	3.0	4
012a.1	0	1	65.8	3.9	6
012a.1	3.5	1	72.8	6.5	5
012a.1	23	1	64.7	3.6	6
PS1	Pre	1	387.0	16.1	3
PS1	0	1	345.3	9.0	3
PS1	3.5	1	336.5	4.9	2
PS1	23	1	305.0	2.0	3
PS2	Pre	1	1501.0	56.6	2
PS2	0	1	1310.5	20.5	3
PS2	3.5	1	1181.3	36.3	3
PS2	23	1	1154.7	35.1	3
NaCl			<LOD		

4.2.2 CALCIUM: EVIDENCE FOR CATION EXCHANGE

The graphs in Figure 42 exhibit a decrease in soil calcium concentration with increasing salinity, which may suggest the occurrence of cation exchange with the introduction of sodium chloride solution.



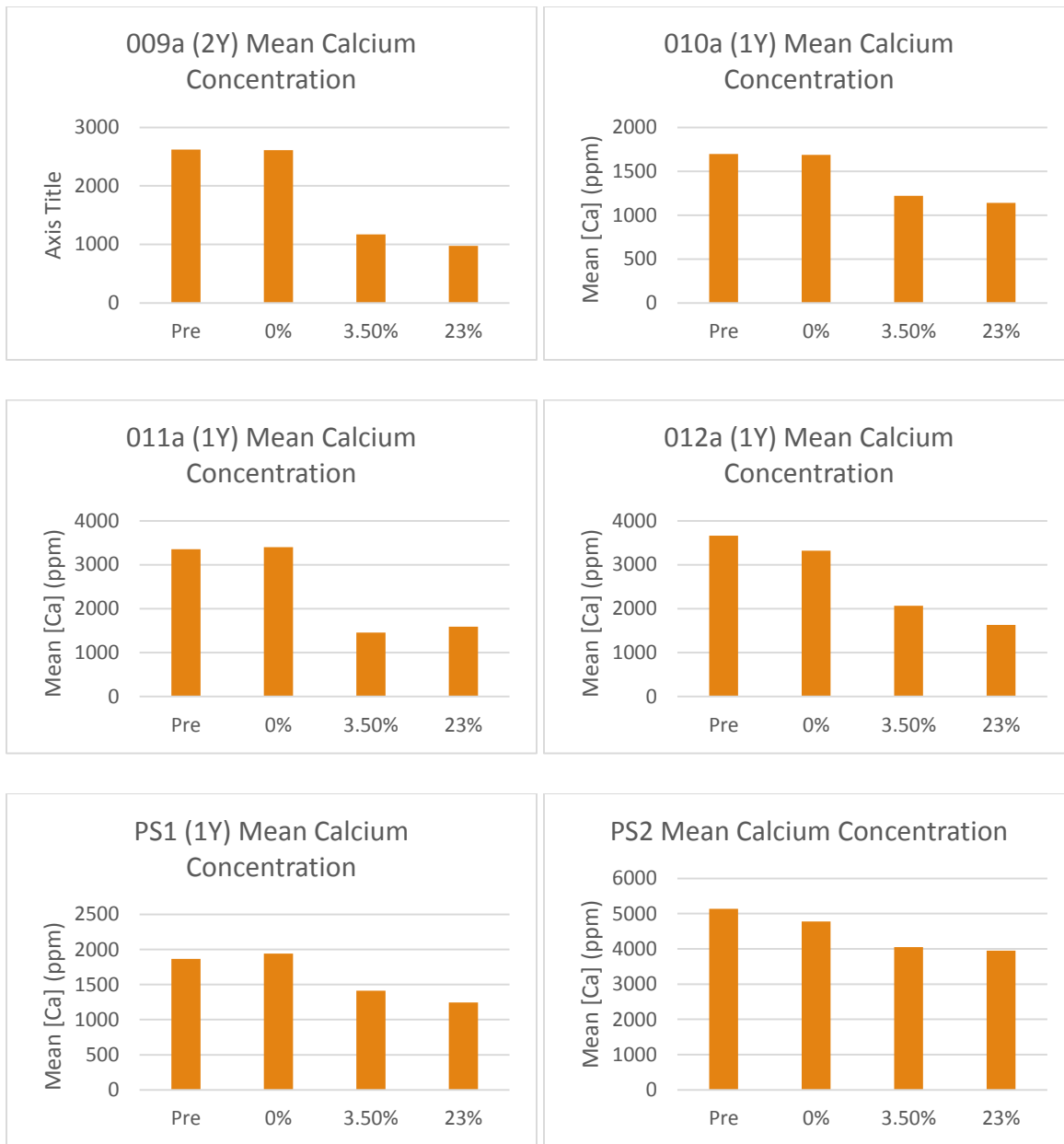


FIGURE 42: MEAN CALCIUM CONCENTRATION OF PHASE TWO - FOUR SOIL SUITES. STANDARD DEVIATION AND NUMBER OF DUPLICATES (N) GIVEN IN TABLE BELOW.

TABLE 7: MEAN CALCIUM CONCENTRATION, STANDARD DEVIATION, AND NUMBER OF DUPLICATES OF PHASE TWO - FOUR SOIL SUITES.

Sample no.	Control	Years	Mean [Ca] (ppm)	St. Dev.	N
005a.1	Pre	2	2121	32.52691	2
005a.2	0	2	2372	84.85281	2
005a.1	3.5	2	1291.4	92.74319	5
005a.1	23	2	1260.25	78.17235	4
006a.1	Pre	2	1572	63.02909	4
006a.1	0		1736.6	67.64096	5
006a.1	3.5	2	1054.6	79.77656	5
006a.1	23	2	1003	69.64673	4
007a	P	1	2708	78.93668	3
007a.1	0	1	3155	63.63961	2
007a.1	3.5	1	1654.5	10.6066	2
007a.1	23	1	1414.5	54.44722	2
007a	P	2	2708	78.93668	3
007a.2	0	2	2755.5	43.13351	2
007a.2	3.5	2	1393.5	13.43503	2
007a.2	23	2	1324.5	92.63099	2
008a.1	Pre	1	3075.5	184.5549	2
008a.1	0	1	3024.5	126.5721	2
008a.1	3.5	1	1912	29.69848	2
008a.1	23	1	1678.5	205.7681	2
009a.1	Pre	1	2622.5	102.4256	4
009a.1	0	1	2417	26.87006	2
009a.1	3.5	1	931	12.72792	2
009a.1	23	1	1043.333	73.00913	3
009a.3	Pre	2	2620	79.19596	2
009a.3	0	2	2610	28.28427	2
009a.3	3.5	2	1172.333	89.2263	3
009a.3	23	2	977.5	38.89087	2
010a.1	Pre	1	1696	220.6173	2
010a.1	0	1	1687.5	7.778175	2
010a.1	3.5	1	1221	45.25483	2
010a.1	23	1	1139.8	69.47446	5
011a.1	Pre	1	3355.5	217.0818	2
011a.1	0	1	3399	39.59798	2
011a.1	3.5	1	1455.5	44.54773	2
011a.1	23	1	1588.5	70.00357	2
012a.1	Pre	1	3665	87.71925	4
012a.1	0	1	3318	53.78104	6
012a.1	3.5	1	2067	139.2875	5
012a.1	23	1	1630.5	224.0542	6
PS1	Pre	1	1865.667	119.4418	3
PS1	0	1	1941.333	24.58319	3
PS1	3.5	1	1411.5	2.12132	2
PS1	23	1	1244	120.3869	3
PS2	Pre	1	5140.5	33.23402	2
PS2	0	1	4779	205.1512	3
PS2	3.5	1	4053	68.63672	3
PS2	23	1	3948	310.0387	3

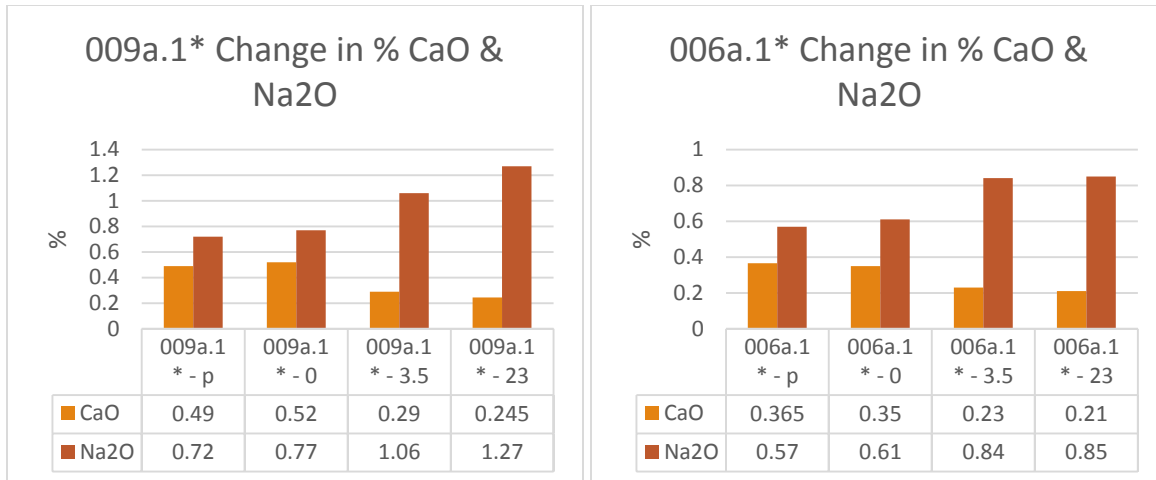


FIGURE 43: DECREASE IN CAO AND ASSOCIATED INCREASE IN NA2O FOR PHASE ONE SOIL SUITES.

4.2.3 EVIDENCE FOR ORGANIC MATTER MOBILIZATION

The colour trends documented in Figure 44 were noted for several of the experiments. Initially (with the first 200 mL or so of solution), the 0% control had the darkest leachate. As more water was added the 23% control progressively became the darkest. Upon switching from a 200 mL to 1000 mL flask, a layering effect can be observed in the leachate in the larger flask, with a similar trend.





FIGURE 44: GRADATIONAL DARKENING OF LEACHATE FROM 0% TO 23% CONTROL OBSERVED IN SEVERAL OF THE LEACHING EXPERIMENTS. SUGGESTS ORGANIC MATTER MOBILIZATION.

CHAPTER 5: DISCUSSION

The observed decrease in lead concentrations in samples with elevated concentrations (PS1 and PS2) may be related to the proportion of labile lead in the sample. When concentrations are lower, lead is likely bound in mineral phase and less available to be leached. Conversely, when lead concentrations are initially high, a greater proportion of lead is labile and more can be leached. The same observations are made for zinc. It appears, in the samples with high concentrations, that the decrease in concentration becomes larger as the concentration of sodium chloride added increases.

5.1 SOURCES OF VARIABILITY IN DATA

Sources of variability in the data may include soil inhomogeneity, introduction of metals from road salt (such as in the case of copper), and analytical error including potential interference of introduced sodium.

5.2 FACTORS IN MOBILIZATION

Factors in mobilization include the mobile (labile) element amount, soil/solution pH, redox potential, proportion of clay, proportion of oxides, and dissolved organic carbon (organic matter). Different metals react differently to each parameter. For example, Zn mobilization depends highly on the amount of Zn present and the soil pH, but not as strongly on organic matter content and DOC; conversely mobilization of Cu and As have a greater association with DOC (Kalbitz & Wennrich, 1998).

5.3 SUPPORT FOR THE OCCURRENCE OF METAL MOBILIZATION

Four mechanisms considered to be involved in the mobilization of metals are ion exchange, such as between calcium and sodium, decreased pH, formation of chloride complexes, and colloid dispersion (Backström et al., 2003). Other mechanisms include organic matter mobilization (Amrhein et al., 1992) and physical remobilization by disturbance to the soil. (Turer & Maynard, 2002). Precipitation of metals such as lead and zinc with phosphate or sulfate may also account for changes in concentrations (Amrhein et al., 1994; Acosta et al., 2011).

The results of the leaching experiments support the occurrence of cation exchange with calcium, and organic matter mobilization. Calcium concentrations decrease in all sample suites, from 0% to 23% NaCl, and at least in the phase one suites, are associated with an increase in sodium, suggesting an exchange between calcium and sodium; no sodium analysis is available for suites 2 - 4. A gradual darkening of the leachate from the 0% to 23% control suggests the occurrence of organic matter mobilization. A decrease in certain metal concentrations, including lead and zinc, particularly when initial concentrations are high, further supports the occurrence of metal mobilization. It appears that mobilization is most notable when there is a high concentrations of a metal, and therefore not all is bound in mineral phase.

5.3.1 CATION EXCHANGE

The graphs in Figure 42 demonstrate a decrease in mean calcium concentration in all sample suites following the addition of sodium chloride. This suggests the occurrence of cation exchange, in which a calcium cation is replaced by two sodium cations from the sodium chloride solution. This concept is illustrated in Figure 45. Additionally, provided there is a great enough labile amount of a metal, such as lead, an exchange may occur between the chloride and the metal, as shown in the first situation (top) of Figure 45. When metal concentrations are low in the soil, the metals are more likely to be bound in solid phase. Backström et al. (2003) and Acosta et al. (2011) found cation exchange to be a key mechanism in the mobilizations of zinc. Some, but not all leaching experiments in this study showed a decrease in mean zinc concentrations (Figure 40 & Figure 41).

Only the two sample suites from phase one were analyzed for sodium, as the portable XRF used for phases 2-4 does not analyze for sodium. For these two, the decrease in the percentage of calcium oxide is associated with an increase in the percentage of sodium oxide, further supporting the occurrence of cation exchange between sodium and calcium (see Figure 43).

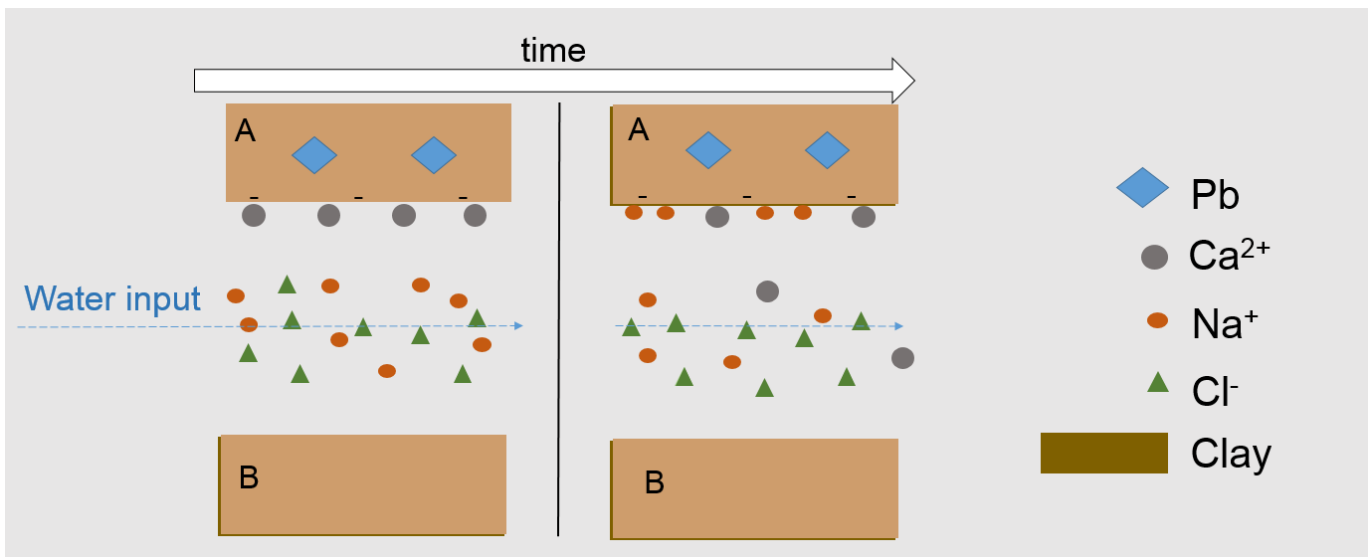
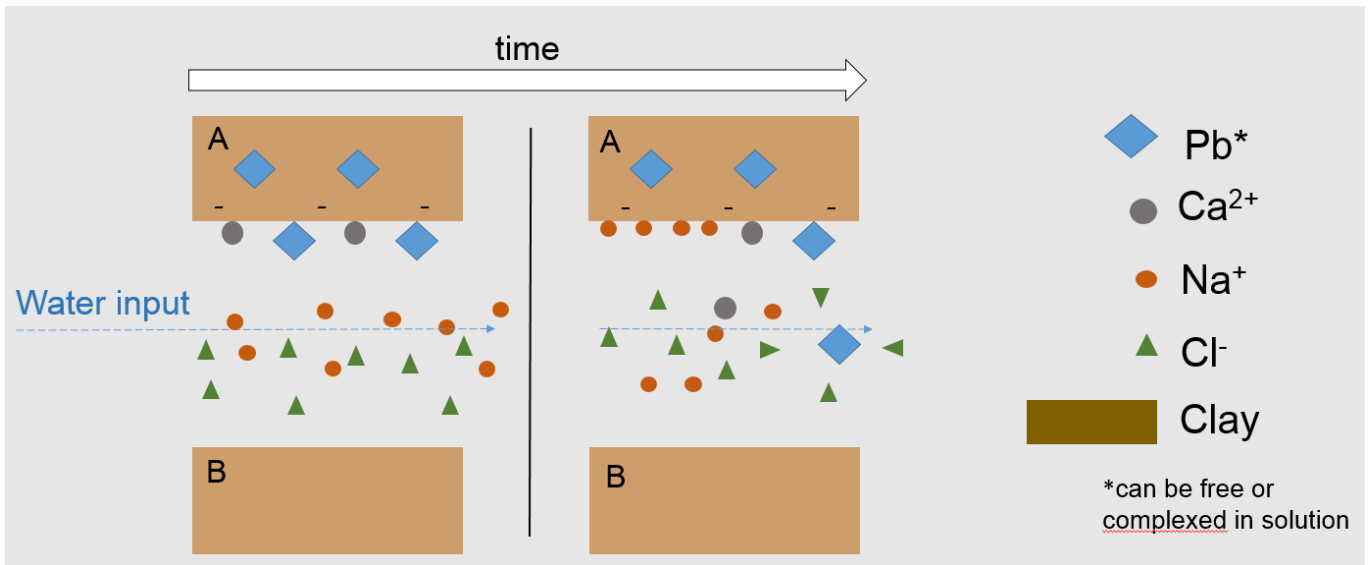


FIGURE 45: SCHEMATIC DIAGRAMS FOR TWO SITUATIONS OF CATION EXCHANGE. ELEVATED PB, MORE LABILE (TOP); LOWER PB, LESS LABILE (BOTTOM)

5.3.2 ORGANIC MATTER MOBILIZATION

The colour trends seen in Figure 44 are likely related to the amount of organic matter, including macro and microorganisms and vegetative matter, in the sample and the mobilization thereof; along with the potential associated mobilization of metals, such as lead (Amrhein & Strong, 1990; Amrhein et al. 1992, 1994; Backström et al., 2003). Turer & Maynard (2002) note a strong correlation between organic matter and anthropogenic substances, including lead. The observed layering effect may suggest that it is upon flushing of the soil/salt with distilled water (or rain/spring melt in the natural world) that elements mobilization occurs.

5.4 ALTERNATIVE EXPLANATIONS FOR FEWER METALS IN ROADSIDE SOIL

In addition to mobilization of metals by chloride from road salts, there are other possible explanations for the lower roadside than ambient metal values noted in residential Halifax soils by Archibald et al., 2014. First of all, roadsides are commonly more vulnerable to erosion than their ambient or dripline counterparts, due in part to human traffic and construction. Furthermore, depressions in terrain are often found on roadsides, allowing for the accumulation of water and therefore a greater influx to the soil and potentially greater leaching (See Figure 46). The presence or lack of vegetation can impact the metal concentrations. Lack of vegetation increases risk of erosion. Abundant vegetation may result in uptake of metals by plants, or leaching of metals from soil by organic acids, such as fulvic acid (Baker, 1973). Lastly, metals used for treating lumber or other construction materials are more commonly associated with dripline or ambient samples, where fences or other infrastructure may be more common than alongside a road.



FIGURE 46: GREATER EROSION AND POOLING OF WATER ALONG ROADSIDES MAY ACCOUNT IN PART FOR LOWER METAL CONCENTRATIONS IN ROADSIDE SOILS.

CHAPTER 6: CONCLUSIONS

Metals can be introduced to soils through various geologic or anthropogenic processes. Particular contaminants, including lead are often found in elevated concentrations in soils of older cities, such as Halifax, having been deposited from leaded gasoline emissions or the weathering or improper removal of leaded paint. Depending on bioaccessability, lead and other heavy metals can negatively impact human and wildlife health, as well as overall groundwater and soil quality. Many metals in Halifax exceed CCME guidelines for residential soils, with roadside soils having typically lowest concentrations for several metals. This was proposed by Archibald et al. (2014) to be potentially attributable to mobilization of metals by road salt, through chloride leaching. The application of road salt is critical in winter months to ensure human safety and economic productivity, however it has associated detrimental effects. Because of the risk that road salts pose to overall ecosystem health the establishment of better management practices, such as that in the HRM, are important. In addition to detriment to vegetation, wildlife, water and soil quality; road salts have been shown to affect mobilization of certain metals, including zinc and lead. (Amrhein & Strong, 1990; Amrhein et al., 1992, 1994; Bäckström et al., 2002; Acosta et al., 2011). The amount of mobilization appears to be related to the initial concentration of the metal in the soil, and the labile proportion. Main mechanisms involved in the mobilization of metals with the introduction of sodium chloride are ion exchange, such as between calcium and sodium, decreased pH, formation of chloride complexes, and colloid dispersion (Backström et al., 2003). Other mechanisms include organic matter mobilization (Amrhein et al., 1992) and physical remobilization by disturbance to the soil. (Turer & Maynard, 2002). A decrease in calcium observed for all soil suites supports the occurrence of cation exchange. The occurrence of organic matter mobilization is supported by observed leachate colour trends, which darken from the 0% to 23% control. In conclusion, the application of a sodium chloride solution to soils does mobilize select metals, including lead and zinc, provided a sufficient labile proportion. Mechanisms involved include cation exchange and organic matter mobilization.

6.1 RECOMMENDATIONS FOR FUTURE WORK

In future leaching experiments of this type it is recommended that the sodium chloride be flushed out with more distilled water than in this study, to minimize the potential interference of sodium in the XRF analysis. In addition, leaching experiments ran for the equivalent of five or

ten years may yield greater insight to leaching over a longer period of time, giving a better representation of leaching over several seasons of sodium chloride loading.

It is recommended that a more comprehensive textural classification be done in future work. Correlation between soil texture, particularly the clay fraction, and proportion of a given metal mobilized may yield further insight into the impact of texture on mobilization. It has been shown that soils with higher proportions of clay and silt can increase metal retention (Burgos, 2008). In addition to the clay fraction, a quantitative analysis of dissolved organic carbon (DOC) could support the involvement of organic matter in the leaching of metals.

Heavy metal analysis of soil in other parts of the HRM is recommended. It is recommended that samples be collected in the North end of the Halifax Peninsula, with consideration of the Goldenville formation, the Africville landfill, and the modern industrial areas. Samples taken near the Tufts Cove Generating Station in Dartmouth could provide useful insight into how electricity generation in the HRM affects the local soils.

It is also recommended that samples be taken in the spring, following the melting of the snowpack, and again in the fall to determine if metal concentrations vary seasonally. Samples are recommended to be taken in incremental transects from the road, to try to determine the spatial extent, if any, of the variability.

APPENDIX

TABLE 8: SITE AND SAMPLE CHARACTERISTICS

Field Characteristics												
Date	Time	Location	Station ID	Slope	Aspect	Depth (cm)	Width (cm)	Colour	Texture (Field description)	Vegetation	Land use	Other notes
10-Nov-14	11:00 AM	Sexton Campus: between cemetery and gym	2014-JV-005a	07°	ENE	10	20	blackish brown	silty clay loam	grass; decid. trees	green space	above depth of graveyard; abundance of worms
			2014-JV-005b	"	"	5	20	"	"	"	"	"
	11:35 AM	By gazebo, adjacent to cemetery and courthouse	2014-JV-006a	04°	SE	10	20	brown; red reducing layer (at ~ 5cm)	sandy loam	"	"	downslope of drain
			2014-JV-006b	"	"	5	20	"	"	"	"	"
	12:05 PM	Adjacent to building on Barrington/Morris, top of hill beside parking driveway	2014-JV-007a	20°	SE	10	20	medium brown	[gravelly] sandy clay loam	"	green space; beside road	red ants; on hill
			2014-JV-007b	"	"	5	20	"	"	"	"	"
	12:30 PM	Bottom of ^ hill; closer to Morris St sidewalk	2014-JV-008a	24°	E	10	20	medium brown	loamy sand	grass; decid. trees; shrubs upslope	green space; beside sidewalk	abundance of snails, worms; bottom of hill
			2014-JV-008b	"	"	5	20	"	"	"	"	"

Time	Location	Station ID	Slope	Aspect	Depth (cm)	Width (cm)	Colour	Texture	Vegetation	Land Use	Other Notes
9:20 AM	Park at South/Oxford	2014-JV-009a	1	SW	10	20	dark brown	clay-rich	grass; leaves	Park	
9:40 AM	Between Sheriff Hall and LSC	2014-JV-010a	2	SW	10	10	light-med redish brown	sandy loam?	decid. Trees; tall grass; "weeds"	Green space	Downslope of walking path
11:00 AM	Ocean pond, close to chem building wall under ocean	2014-JV-011a			10	20	light-med brown	sandy clay loam?	grass, decid. Trees, shrubs	green space	bumpy terrain
11:55 AM	pond fence adjacent to sidewalk	2014-JV-012a			10	20	medium brown	gravelly, sandy	decid. Trees; grass; detritus	green space	



FIGURE 47 JV-005A AND JV-006A LEACHING EXPERIMENTS AFTER 200 ML OF SOLUTION



FIGURE 48 JV-005A AND JV-006A LEACHING EXPERIMENTS AFTER 600 ML OF SOLUTION



FIGURE 49 JV-005A AND JV-006A LEACHING EXPERIMENTS AFTER 11300 ML OF SOLUTION

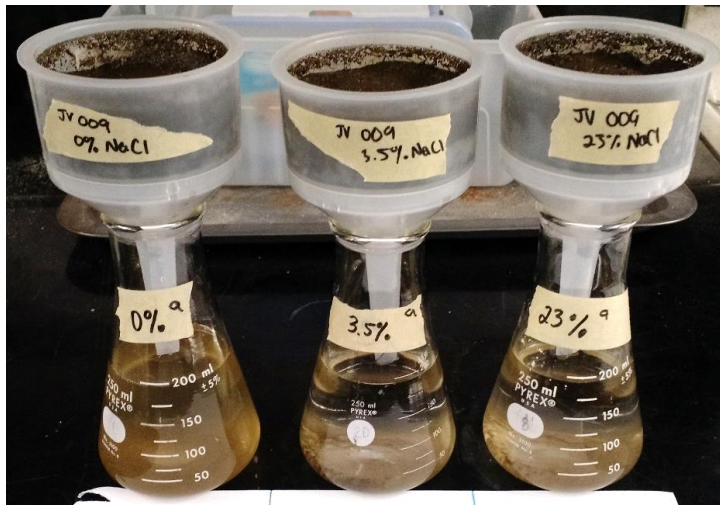


FIGURE 50 JV-009 LEACHING EXPERIMENT AFTER 200 ML OF SOLUTION

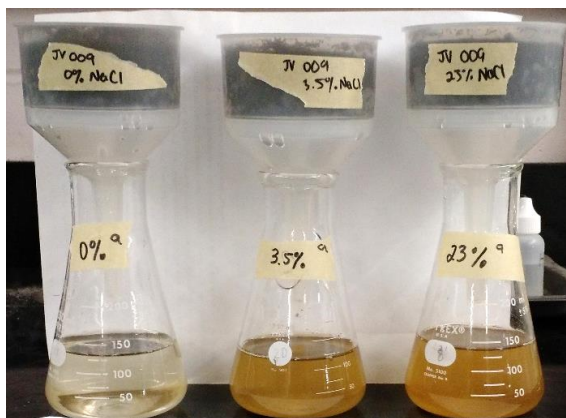


FIGURE 51 JV-009 LEACHING EXPERIMENT AFTER 565 ML OF SOLUTION

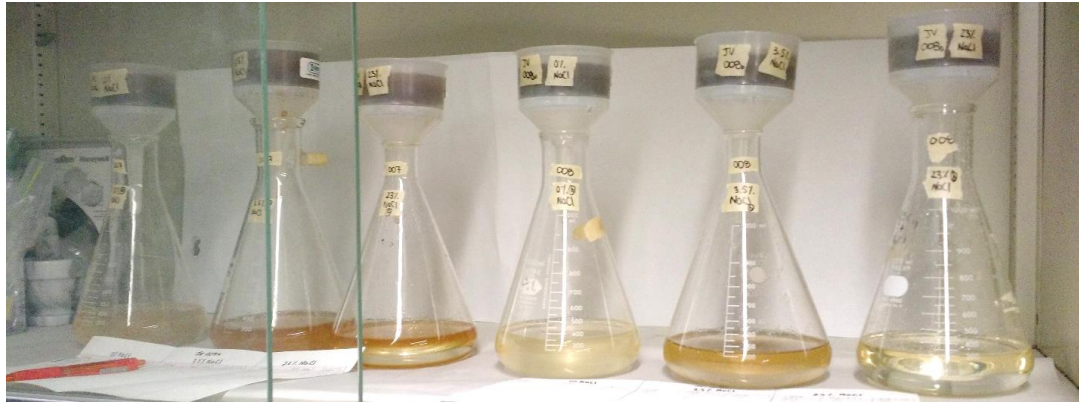


FIGURE 52 JV-007 AND JV-008 LEACHING EXPERIMENTS AFTER 300 ML OF SOLUTION. NOTE LAYERING OF DIFFERENT COLOURED LEACHATE.

REFERENCES

- Acosta, J.A., Jansen, B., Kalbitz, K., Faz, A., Martinez-Martinez, S. 2011. Salinity increases mobility of heavy metals in soils. *Chemosphere*, **85**: 1318-1324.
- Archibald, J., Broom, L., Desjardins, V., Minichiello, J., and Ryan, A. M. 2014. Heavy Metal Concentrations in Residential Soils within the Halifax Peninsula, NS, Canada: A Pilot Study. Poster session presented at The Atlantic Geoscience Society (AGS) 40th Colloquium and Annual Meeting. 2014 7-9 February; Greenwich, Nova Scotia.
- Amrhein, C. and Strong, J.E. 1990. The Effect of Deicing Salts on Trace Metal Mobility in Roadside Soils. *Journal of Environmental Quality*, **19**: 765-772.
- Amrhein, C., Strong, J.E., and Mosher, P.A. 1992. Effect of deicing salts on metal and organic matter mobility in roadside soils. *Environmental Science & Technology*, **26(4)**: 703-709.
- Amrhein, C., Mosher, P.A., Strong, J.E., and Pacheco, P.G. 1994. Trace Metal Solubility in Soils and Waters Receiving Deicing Salts. *Journal of Environmental Quality*, **23(2)**: 219-227.
- Bacigalupo, C. and Hale, B. 2012. Human health risks of Pb and As exposure via consumption of home garden vegetables and incidental soil and dust ingestion: A probabilistic screening tool. *Science of the Total Environment*, **423**: 27-38.
- Bäckström, M., Karlsson, S., Bäckman, L., Folkesson, L. and Lind, B. 2003. *Water Research*, **38**: 720-732.
- Baker, W.E. 1973. The role of humic acids from Tasmanian podzolic soils in mineral degradation and metal mobilization. *Geochimica et Cosmochimica Acta*, **37(2)**: 269-281.
- Bell, T., Campbell, S., Liverman, D.G.E., Allison, D., and Sylvester, P. 2010. The Environmental and Human Health Legacies of Non-Industrial Sources of Lead in a

Canadian Urban Landscape – the Case Study of St. John's, Newfoundland. *International Geological Review*, **52**: 7-8, 771-800.

- Bester, M. L., Frind, E. O., Molson, J. W., and Rudolph, D. L. 2006. Numerical Investigation of Road Salt Impact on an Urban Wellfield. *Groundwater*, **44(2)**: 165-175.
- Bird, M.J. 1995, 2011. *The Town that Died: A Chronicle of the Halifax Explosion*. Nimbus Publishing Limited, Halifax, N.S.
- Brooks, B. ca. 1965. About 15 Africville houses, with a well and nearby sign reading, "Please boil this water before drinking and cooking". Bob Brooks NSARM accession no. 1989-468 vol. 16 / negative sheet 6 image 31.
- Brooks, B. ca. 1965. Two young girls picking blueberries, Africville. Bob Brooks NSARM accession no. 1989-468 vol. 16 / negative sheet 4 image 15.
- Brooks, B. ca. 1965. Halifax city dump with Seaview African United Baptist Church and Africville houses in the background. Bob Brooks NSARM accession no. 1989-468 vol. 16.
- Burgos, P., Madejon, E., Perez-de-Mora, A., and Cabrera, F. 2008. Horizontal and vertical variability of soil properties in a trace element contaminated area. *International Journal of Applied Earth Observations*, **10**: 11-25.
- CCME. 2013. *Soil Quality Guidelines for the Protection of Environmental and Human Health (2013 update)*. Canadian Council of Ministers of the Environment.
- CEPA, 1999. *Canadian Environmental Protection Act*.
- Chaney, R.L., Sterrett, S.B., and Mielke, H.W. 1984. The potential for heavy metal exposure from urban gardens and soils. J.R. Preer (ed.) *Proc. Symp.* 37-84
- Chemistry Explained. n.d. Steel [online]. Available from <http://www.chemistryexplained.com/St-Te/Steel.html>. [cited 20 March 2015].

- Clark, H.F., Hausladen, D.M., and Brabander, D.J. 2008. Urban gardens: Lead exposure, recontamination mechanisms, and implications for remediation design. *Environmental Research*, **107(3)**: 12-319.
- ClimaTemps.com. n.d. Halifax, Nova Scotia Climate & Temperature [online]. Available from <http://www.halifax.climatemps.com/> [cited 20 March 2015].
- Clorox. 1999. Glad bags [Material Safety Data Sheet]. Available from <http://www.thecloroxcompany.com/downloads/msds/glad/gladbags.pdf> [cited 20 March 2015].
- DISP: Dalhousie Integrated Science Program. 2014. Heavy Metal Mobilization in Halifax Soils and the Role of De-icing Salts. In-Class Study. Unpublished.
- Donohoe, H.V. Jr., White, C.E., Raeside, R.P. and Fisher, B.E. 2005. Nova Scotia Geological Highway Map, Third Edition. Atlantic Geoscience Society.
- Environment Canada. 2000. Priority Substances List, Road Salts: Assessment Report and Supporting Documentation, Environment Canada.
- Environment Canada. 2004. Code of Practice for the Environmental Management of Road Salts. Environment Canada.
- Environment Canada. 2013. Coal [online]. Available from <https://www.ec.gc.ca/energie-energy/default.asp?lang=En&n=21FAF93C-1> [cited 20 March 2015].
- Environment Canada. 2013. Nova Scotia Power Incorporated - Tufts Cove Generating Station [online]. Available from http://ec.gc.ca/inrp-npri/donnees-data/index.cfm?do=facility_substance_summary&lang=en&opt_npri_id=0000003998&opt_report_year=2013 [cited 20 March 2015].
- Foley, R., Bell, T., & Liverman, D. 2011. Urban Geochemical Hazard Mapping of St. John's, Newfoundland, Canada. *Atlantic Geology*, **47**: 138-157

- Fox, D. L. 1999. Prediction of acid rock drainage (ARD) from sulphidic slates using GIS analysis of mineralogical, geochemical, magnetic and geological parameters a test case in southern Nova Scotia; unpublished Ph. D. thesis, Dalhousie University, Halifax, N.S.
- Gauvin and Gentzel. 1918. Collapsed buildings of Nova Scotia Car Works on Clifton Street near St. Albans Street, Halifax, with Bloomfield School in background at right. Charles Vaughan NSARM / negative: N-7036.
- Goodwin, T.A. 2003. Soil and Till Geochemistry of the Halifax Regional Municipality, Nova Scotia. *In* Mineral Resources Branch, Report of Activities 2002; Nova Scotia Department of Natural Resources, Report 2003-1:41-47.
- Google Earth. 2014. Halifax Peninsula. 44°38'43.59"N 63°35'41.86"W. September 7, 2014 [cited 16 March 2015].
- Google Earth. 2014. Sample Site Locations. 44°38'25.63"N 63°35'00.24"W. Google Earth. September 7, 2014 [cited 16 March 2015].
- Haysom, S.J. 1994. The opaque mineralogy, petrology, and geochemistry of the Meguma Group metasediments, Rawdon area, Nova Scotia. Unpublished BSc. Thesis. St. Mary's University, Halifax, Nova Scotia.
- Health Canada. 2013. Final Human Health State of the Science Report on Lead [online]. Available from <http://www.hc-sc.gc.ca/ewh-semt/pubs/contaminants/dhhssrl-rpecscepsh/index-eng.php> [cited 20 March 2015].
- Jenny, H. 1941. Factors of soil formation: A system of quantitative pedology (1st ed., McGraw-Hill publications in the agricultural sciences). McGraw-Hill, New York.
- Halifax Regional Municipality. 2014. Salt Management Strategies [online]. Available from <http://www.halifax.ca/snow/SaltManagementStrategies.php> [cited 20 March 2015].
- Heidary-Monfared, S. 2011. Community Garden Heavy Metal Study.

- Jacobs, D.E., Mielke, H., and Pavur, N. 2003. The High Cost of Improper Removal of Lead-Based Paint from Housing: A Case Report. *Environmental Health Perspectives*, **111(2)**: 185-186.
- Jain, P., Kim, H., Townsend, T.G. 2004. Heavy metal content in soil reclaimed from a municipal solid waste landfill. *Waste Management*, **25(1)**: 25-35.
- Jonker, C. & Olivier, J. 2012. Mineral Contamination from Cemetery Soils: Case Study of Zandfontein Cemetery, South Africa. *International Journal of Environmental Research and Public Health*, **9(2)**: 511-520.
- Kalbitz, K. and Wennrich, R. 1998. Mobilization of heavy metals and arsenic in polluted wetland soils and its dependence on dissolved organic matter. *Science of the Total Environment*, **209(1)**: 27-39.
- Keys, K. 2007. Forest Soil Types of Nova Scotia. Identification, Description, and Interpretation. Nova Scotia Department of Natural Resources.
- MacDougall, J. I., Cann, D. B., Hilchey, J. D., & Nova Scotia Soil Survey (Canada). 1963. Map Soil survey of Halifax County [West Sheet], Nova Scotia. 1: 63,360 Canada Dept. of Agriculture and Nova Scotia Dept. of Agriculture and Marketing, Ottawa, ON. Available from <http://sis.agr.gc.ca/cansis/publications/surveys/ns/ns13b/index.html> [cited 20 March 2015].
- MacPherson, T.J. 1987. Abandoned Waste Disposal Site Study: Province of Nova Scotia. Halifax: Nova Scotia Department of the Environment.
- Markus, J. A., and McBratney, A. B. 1996. An urban soil study: Heavy metals in Glebe, Australia. *Australian Journal of Soil Research*, **34(3)**: 453-465.
- McCully, R. 1931. Imperial Oil with Tanker (Halifax, Nova Scotia). Nova Scotia Archives accession no. 2012-010/003 no. 1 | negative no. 168.

- Mielke, H. W., Gonzales, C. R., Powell, E. T., and Mielke, P. W. (2013). Environmental and health disparities in residential communities of New Orleans: The need for soil lead intervention to advance primary prevention. *Environment International*, **51(6)**: 73-81.
- N.S. Board of Insurance Underwriters. 1918. Plan showing devastated area of Halifax City, N.S. N.S. Board of Insurance Underwriters NSARM V6/240 - 1917 Halifax loc.4.2.3.2 / negative: O/S N-111.
- Nova Scotia Bureau of Information. 1956. Lathe workers, Halifax Shipyards. Nova Scotia Information Service NSARM no. 9145 / neg. no.: 9145.
- Nova Scotia Communities, Culture and Heritage. 2010. Halifax Explosion Remembrance Book [online]. Available from <http://novascotia.ca/archives/virtual/remembrance> [cited 20 March 2015].
- Nova Scotia Museum of Natural History. 1996. Natural History of Nova Scotia, Vol. 1. Nova Scotia Museum of Natural History, Halifax, N.S. pp. 176-183.
- Nova Scotia Power¹. 2015. Who We Are: Our History [online]. Available from <http://www.nspower.ca/en/home/about-us/who-we-are/our-history.aspx> [cited 20 March 2015].
- Nova Scotia Power². 2015. How We Make Electricity [online]. Available from <http://www.nspower.ca/en/home/about-us/how-we-make-electricity/default.aspx> [cited 20 March 2015].
- Pandey, V.C. and Singh, N. 2010. Impact of fly ash incorporation in soil systems. *Agriculture, Ecosystems and Environment*. **136**: 16-27.
- Rutz, E., Valentine, J., Eckart, R., and Yu, An. 1997. Pilot study to determine levels of contamination in indoor dust resulting from contamination of soils. *Journal of Soil Contamination*, **6(5)**.

- Schwarz, K., Pickett, S.T.A., Lathrop, R.G., Weathers, K.C., Pouyat, R.V., and Cadenasso, M.L. 2012. The effects of the urban built environment on the spatial distribution of lead in residential soils. *Environmental Pollution*, **163**: 32-39.
- Shaheen, S.M, Hooda, P.S., Tsadilas, C.D. 2014. Opportunities and challenges in the use of coal fly ash for soil improvements. *Journal of Environmental Management*, **145**: 249-267
- Sifto. 2011. Sifto Safe Step Standard Salt Ice Melter. [Material Safety Data Sheet]. Available from http://www.siftocanada.com/media/filer_private/2011/06/24/sifto-safe-step-standard-salt-english-msds-jan11.pdf [cited 28 April 2015].
- Stantec Consulting Ltd. 2011. Road Salt – Review of Best Management Practices. Draft Report. Stantec Consulting Ltd. Dartmouth, N.S.
- Turer, D.G. and Maynard, J.B. 2003. Heavy metal contamination in highway soils. Comparison of Corpus Christi, Texas and Cincinnati, Ohio shows organic matter is key to mobility. *Clean Technologies and Environmental Policy*, **4**: 235-245.
- U.S. EPA, Office of Solid Waste and Emergency Response, Office of Resource Conservation and Recovery. 2010. Human and Ecological Risk Assessment of Coal Combustion Wastes. Draft EPA document.
- Utting, D.J. 2011. Overview Map Showing Locations of Surficial Geology Maps of the Halifax Metropolitan and Surrounding Areas, Halifax and Hants Counties, Nova Scotia. Nova Scotia Department of Natural Resources. Mineral Resources Branch. Map ME 2011-001. Scale 1:100 000
- Waldron, J.W.F., Jamieson, R.A., Pothier, H.D., White, C.E. 2015. Sedimentary and tectonic setting of a mass-transport slope deposit in the Halifax Group, Halifax Peninsula, Nova Scotia, Canada. *Atlantic Geology*, **51**: 84-104.

- White, C.E., Bell, A., McLeish, D.F., MacDonld, M.A., Goodwin, T.A., and Macneil, J.D. 2008. Geology of the Halifax Regional Municipality, Central Nova Scotia. *In* Mineral Resources Branch, Report of Activities 2007. Nova Scotia Department of Natural Resources, Report, ME 2008-1: 125-139.
- Whiting, D., Wilson, C., and Reeder, J. 2014. Estimating Soil Texture: Sand, Silt or Clayey? [online]. Available from <http://www.ext.colostate.edu/mg/gardennotes/214.html> [cited 20 March 2015].
- Ximing, L., Jiajun, K., Xinhui, M., and Bin, L. 1992. Chlorine leaching of gold-bearing sulphide concentrate and its calcine. *Hydrometallurgy*, **29**: 205-215.