Investigation of Heavy Metals in a Green Space Corridor: Sources, Health Concerns and Mitigation Strategies

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Executive Summary

Globally, cities utilize green spaces to serve a variety of functions for the community and environment. As urbanization increases, so does the demand for multifunctionality of limited green spaces. However, as urbanization intensifies, so does contamination associated with urban development into these green spaces. One related concern is heavy metal exposure for humans in green spaces associated with community gardens, urban agriculture and children's play spaces. This becomes an issue when heavy metals enter the soil, are taken up by vegetable plants and are then consumed by humans or when children play in soils with heavy metals and are exposed through dermal contact or inhalation of dust.

This white paper first reviews the literature concerning both sources of heavy metal contaminants in urban agriculture and green spaces and current remediation/prevention methods available. Secondly, it uses a section of the Arbutus Corridor in Vancouver as a case study to assess contamination of heavy metals in community gardens, the surrounding native soil and whether a number of physical barriers adjacent to a traffic corridor prevent or limit the contamination of heavy metals into the community garden's soils and vegetation.

The literature review revealed that heavy metal contamination is a concern in areas with high traffic density. Moreover, there is a potential for certain perennial species studied in Vancouver to phytostabilize (immobilize heavy metals) in their plant roots, including Kentucky Bluegrass, Perennial Rye Grass and Creeping Red Fescue.
The assessment of a site in the Arbutus Corridor revealed that plant available heavy metals were low enough for the area to be safe for production of vegetables, except for the first garden site. This site had levels of lead that exceed the Canadian Council of Ministers of the Environment's (CCME) threshold considered safe for agricultural production. However, this lead was not present in the native soil located adjacent to the community garden. This highlights the need for testing not only of the native soil, but also of imported topsoil for gardens. Distance from the traffic corridor was correlated with lower levels of most heavy metals found in the soil. Potential barriers to prevent movement of heavy metals into gardens could include vegetation ditches and trees, however, more research is required.

It is suggested that city planners assess the potential of heavy metal contamination, including testing native soil and imported soil as part of the determination of new community garden sites and plans. When conducting this assessment, consider factors that will contribute to heavy metal contamination overtime, including site location and history; proximity to traffic/industry; density of traffic; and the parent material of the soil. Secondly, consider the potential for the physical movement of heavy metals resulting in deposition to the selected site; wind carrying atmospheric particles and runoff associated with sloping topography and rain. Thirdly, factors affecting the bioavailability of heavy metals: climate, pH, organic matter. Barriers should be assessed for their role in limiting the movement of heavy metals in the soil. Lastly, continue monitoring of soil and vegetation heavy metal concentrations overtime to ensure continued safe levels.

1. Introduction:

Urban Green Spaces

Green spaces in urban areas are highly valued for the number of services they provide. There is a demand for them to be multifunctional due to the diverse benefits they can provide for the community and the environment (Stoltz and Schaffer, 2018). For example, they support social cohesion by providing space for play and community gathering (Stoltz and Schaffer, 2018; Thomas and Lavkulich, 2015). Moreover, they serve a number of ecological benefits, including but not limited to: biodiversity, water regulation and carbon sequestration. (Stoltz and Schaffer, 2018). There is an increasing demand for and use of these spaces for urban food production (Thomas and Lavkulich, 2015; Laidlaw et al. 2018). It has become progressively popular as a way to contribute to local food security, with the goal of supplying healthy, affordable food while also providing opportunities to strengthen community connection (Thomas and Lavkulich, 2015; Laidlaw et al.,2018; Kessler 2013). These sought-after benefits have resulted in a demonstrable expansion of urban agriculture in many countries (Thomas and Lavkulich, 2015; Laidlaw et al.,2018; Oka et al., 2014). However, as this urban food movement expands, more information is needed to enable urban growers to assess the health risk of their projects. Growing food in an urban environment results in exposures to a number of environmental pollutants associated with urbanization. One of the main contaminant concerns for human exposure is heavy metals (Hamzeh et al., 2011; Thomas & Lavkulich, 2015; Oka et al., 2014; Toronto Public Health, 2011; Laidlaw et al., 2018; Zhou et al., 2016). This requires information on and understanding of how to assess the likelihood of heavy metal contamination in an urban food project at soil concentrations that could be concerning for human health. This is a complex issue as there are many factors affecting human exposure (Oka et al., 2014).

Vancouver is part of a growing food movement, with policies that reflect a desire to increase urban food production (Kessler, 2013; Oka et al., 2014; City of Vancouver, 2012). Heavy metal contamination is a concern for the city, and is a problem exacerbated by the fact that, in the next 25 years, Vancouver is expecting 125,000 more residents (VPB, 2018). This will create challenges, including increased competition between greenspaces and urban development. In addition, greenspaces have the added requirement of suiting the needs of an increasing number of individuals (VPB, 2018). Moreover, urban density is linked to an escalation of both traffic and exposure to contaminants (Pott and Turpin, 1998).

1.1: The Problem: Heavy Metals in Urban Green Spaces and Community Gardens

Heavy metals are defined as elements with metallic properties and densities higher than water, ranging between 3.5-7 g/cm^3 and are toxic at low concentrations (Alloway, 1995). Heavy metals accumulate in the soil, in plants and potentially in the human body (Hamzeh et al., 2011; Laidlaw et al., 2018; Oka et al., 2014).

Heavy metals come from a variety of sources, namely, atmospheric deposition in urban soils associated with traffic pollutants from automobiles (Jolly et al., 2013; Zhou et al., 2016). Other sources of heavy metals in soils include, previous land uses that involved metals; atmospheric deposition from nearby industrial activities; and background levels associated with parent material and industrial activity (Li et al., 2009; Krishna and Govil, 2007; Laidlaw et al., 2018; Oka et al., 2014; Thomas and Lavkulich 2015; Alloway, 1995). These heavy metals become a concern in the soil when they are found in a form that can be taken up by humans, either through inhalation, dermal contact or ingestion (Zhou et al., 2016; Oka et al., 2014). Ingestion of heavy metals from vegetables grown on contaminated soils has been found to be the predominant source of heavy metal uptake in humans (Jolly et al., 2013; Zhou et al., 2016).

1.2 Human Consumption of Heavy Metals:

The ingestion of vegetables from potentially contaminated sites calls into question the safety of urban food production in urban agriculture and community vegetable gardening. There is often a lack of private open spaces for community gardens which results in them frequently being on sites with previous industrial uses and/or close to roadways (Laidlaw et al., 2018). Both occurrences result in the potential for harmful exposure to heavy metal contaminants (Laidlaw et al., 2018; Oka et al., 2014). Zhou et al. (2016), found that prolonged intake of heavy metals, even at low concentrations can have adverse health effects. They can be carcinogenic, cause a number of severe illnesses and result in the dysfunction of a number of body systems and organs (Emenike et al., 2018; Krishna and Govil, 2007; Zhou et al., 2016). This is of increasing concern for children who, due to their more active digestion systems, have higher rates of absorption of heavy metals (Hamzeh et al., 2011). Since children use green spaces for play, their exposure goes beyond consumption and can include both dermal contact as well as inhalation of heavy metals. The possible exposure to heavy metals and associated health risks highlight a potential juxtaposition of the intent for green spaces to provide healthy food and access to fresh air.

2. Literature Review:

a. Summary of the Increasing Concern Heavy Metals Pose

Urbanization results in increased traffic and industrial activities, which signifies a continuous and increasing emittance of heavy metals into the atmosphere and deposition into water and soils (Hamzeh et al., 2011). Not only is heavy metal emittance increasing, they are also persistent in soils. The non-biodegradable nature and long half-lives of these metals provide this potential for accumulation in soils (Hamzeh et al., 2011; Laidlaw et al., 2018). This poses a threat to green spaces that do not currently have significant heavy metal contamination, but which are close to transportation corridors as they may increase to concerning levels with continued exposure. Due to their toxicity at low concentrations, health concerns are present at relatively low concentrations for these metals in the soil (Hamzeh et al., 2011; Laidlaw et al., 2018). Heavy metals at levels below toxicity can cause health issues through repeated exposure and accumulation in both the soil and the human body (Zhou et al., 2016). Pott and Turpin (1998) highlight the following heavy metals as the largest concern for humans as a result of urbanization emittance: arsenic, cadmium, cobalt, chromium, copper, manganese, lead and nickel.

2.1 Potential Sources of Heavy Metals in Green Spaces

As previously identified, traffic is a major source of heavy metal contamination in urban environments. It occurs through exhaust deposits containing metals, wear and tear of brakes, tires and engine parts, as well as leakages (Hamzeh et al., 2011; Laidlaw et al., 2018). The predominant metals released by these mechanisms are: lead, zinc, manganese and copper (Li et al., 2009) In smaller amounts, tin and cadmium can be found from road and automobile sources (Hamzeh et al., 2011) Although lead and manganese were phased out of gasoline additives in Vancouver and many other countries between 1975-1998, their persistence in soils is still relevant and remains a concern for contamination (Oka et al., 2014). Zinc is released by automobiles as a result of wear on rubber in tires and galvanized metal parts (Hamzeh et al., 2013). Copper is released mainly from copper wiring, thrust bearing and brakes (Hamzeh et al., 2013).

Although traffic is a main source of heavy metals in Vancouver's urban environment, there are other relevant sources of heavy metals that can contribute to contamination in urban green space soils. Houses have the potential to contribute to heavy metals in a number of ways. Lead contamination can be found in older housing areas where lead used to be an additive in paints (Laidlaw et al., 2018). Additionally, zinc contamination can occur when runoff occurs from galvanized roofs and drainpipes (LI et al., 2009). Contaminants can be transported through atmospheric deposition and dry deposited on roofs and then remobilized and runoff into soils during storms (Li et al., 2009). Atmospheric deposition from dust and aerosol can also travel from other areas and become an unknown source in soils depending on wind and weather patterns (Li et al., 2009). Other sources include construction materials that were left from the previous land uses when the site was repurposed to a green space (Thomas and Lavkulich, 2015; Krishna and Govil, 2007; Emenike et al., 2018). Lastly, many minerals contain natural levels of metals that with weathering will be released into the soil (Hamzeh et al., 2011)

2.2 Factors Affecting Deposition

Determining where heavy metals will be deposited in soil from their emission source is difficult to predict as there are a number of factors that affect this. Heavy metals emitted from various sources can enter soil through atmospheric deposition or runoff from stormwater (Padmavathiamma and Li, 2009). Typically, heavy metals on a broad scale are positively correlated with the population density of an area as a result of traffic (Pott and Turpin, 1998; Oka et al., 2014). A study by Pott and Turpin (1998) looked at heavy metal movement in mosses and found that heavy metal concentrations within the region of Metro Vancouver declined from west east, which directly correlated to population density and associated urbanization. On a smaller scale, distance of a green space from a major road impacts the distribution of heavy metals, with higher concentrations closer to the road (Pott and Turpin, 1998; Oka et al., 2014) The literature and various municipal recommendations suggest anywhere from 30-100m as the minimum distance separating a community garden from a major road (Oka et al., 2014; Toronto Public Health, 2011) However, it is unclear what traffic densities define a major road. As competition for urban green space intensifies, developing a more defined threshold would be helpful for determining the distance a community garden should be from a road, depending on current and projected traffic.

Assessing heavy metal deposition is increasingly complex as many heavy metals undergo dry deposition on soil particles and can be carried with wind. Their mechanism of entry into the soil is either through dry deposition of these soil particles or deposited with rainfall (Hamzeh et al., 2013). Once in the soil, they can be carried away in heavy rains as runoff either attached to soil particles or in ionic solutions (Hamzeh et al., 2013). Where they are deposited depends on the soil particle size they are bound to: large particles are deposited close to the source of emittance and smaller particles further away (Krishna and Govil, 2007; Oka et al., 2014). Vancouver has two circulating predominating winds blowing northwest and the other going southeast, make determining the location of deposited materials difficult (Pott and Turpin, 1998). The last consideration to be made is the background levels of heavy metals coming from the inherent parent material; if they are already high, lower levels of deposition, such as manganese, could reach a level that if exposed to humans in a bioavailable form, could be of concern (Krishna and Govil, 2007). For example, soils typically high in clay content have higher metal levels as a result of their high adsorption capacity (Alloway, 1995).

Assessing deposition of heavy metals is only the first consideration when determining concerns for human exposure. Only a certain fraction of heavy metals is bioavailable (i.e. mobile), as many metals can become strongly adsorbed and not available for plant uptake (immobile). Therefore, it is the bioavailable form of these metals that are of concern for human contact.

2.3 Soil Conditions Affecting Heavy Metal Availability

There are a number of soil factors that affect the mobility and availability of heavy metals in the soil. The main factors include, organic matter; presence of aluminum and iron hydroxides; pH; redox conditions; and clay content (Emenike et al., 2018). Organic matter may contain chelating exudates which are capable of chelating the metals and making them immobile (Emenike et al., 2018; Hamzeh et al., 2013) Acidic soils release heavy metals from the soil matrix, making them more available, typically when the pH levels are below 5.5 (Emenike et al., 2018; Thomas and Lavkulich, 2015). High clay content and presence of manganese and iron hydroxides increases sorption capacity of the soil rendering heavy metals immobile with similar effects to organic matter (Husson et al., 2016). Low redox potential in the absence of oxygen transfer in the soil results in a release of heavy metals, namely manganese (Hamzeh et al., 2013).

In addition, the elements themselves play a role in their availability based on inherent characteristics. Whereby copper and zinc are two of the more mobile, available metals while lead is typically one of the tightest bound metals in the soil matrix, and therefore often unavailable (Kabata-Pendias, 2011).

2.4 Plant Uptake of Heavy Metals and Phytoremediation

The uptake of heavy metals by plant species depends on their genotype, with certain species being more effective heavy metal accumulators than others (Kabata-Pendias, 2011). Often, the determining factor of heavy metal uptake in plants is the structure of the plant root's cell wall (Gallego et al., 2012). Certain species are more tolerant of heavy metal accumulation, while others have a higher sensitivity and may have reduced growth or die from an accumulation of heavy metals in plant tissues (Tošić et al., 2016). The uptake of heavy metals is important for two reasons in urban green spaces. Firstly, to avoid vegetables that are effective heavy metal accumulators, ensuring that the risk is reduced for heavy metal accumulation within humans. Secondly, to select non-edible plants that have the potential to phytoremediate the heavy metals in the green space.

3.0 Potential Mitigation Strategies to Limit Human Exposure of Heavy Metals in Green Spaces

3.1 Vegetable Species to Avoid when Heavy Metals Present in Soil

There have been a number of vegetable plants that have been identified as high accumulators of heavy metals and should be avoided when heavy metal accumulation in the soil is a concern. These include leafy vegetables such as lettuces and spinaches; root vegetables and amaranth. Whereas low accumulators of heavy metals are within the cucurbit species such as squash, zucchini and cucumbers and could be a safer option in areas with potential heavy metal accumulation in the soil (Zhou et al., 2016). Leafy vegetables were found to be the most susceptible for two reasons. Firstly, their large, leafy surfaces are the areas of photosynthesis, which result in large mass flow movement of metals to those areas (Zhou et al., 2016). Secondly, their low height and the large surface area of the leaves makes them susceptible to atmospheric deposition on their leaf tissue of heavy metals emitted from fuel and brakes, which are emitted low to the ground (Zhou et al., 2016). It is important to understand that washing vegetables is not sufficient to remove heavy metals. Vegetable plants may have some deposition of heavy metals on their leaves, but the majority of heavy metals found in the aforementioned vegetables is a result of soil to root to biomass incorporation (Zhou et al., 2016). Tošić et al., (2016) conducted a study on apple trees and heavy metal accumulation. They found that heavy metals accumulated in apple tree's roots and trunk but very little in the actual fruit and could be a potential option for more heavily contaminated sites (Tošić et al., 2016).

3.2 Phytoremediation: Phytoextraction and Phytostabilization

Phytoremediation is the use of plants to remove, transform, or stabilize pollutants in the soil (Emenike et al., 2016; Padmavathiamma and Li, 2009; Kabata-Pendias, 2011). This provides the potential of planning green spaces with plants such as trees, shrubs and perennials that are heavy metals accumulators as a way to reduce their content in the soil (ie., phytoextraction). Moreover, to restrict the movement of metals or have them in an unavailable, immobile form (ie., phytostabilization), thus optimizing two forms of phytoremediation (Tošić et al et al., 2016; ; Emenike et al.,2018; Padmavathiamma and Li, 2009).

Another method that phytoremediation can be employed is through plants acting as a physical barrier for heavy metals entering a certain area. These plant barriers restrict how far heavy metal deposition can occur, either through trapping atmospheric heavy metals on the shoots of a species or by preventing the erosion and runoff of contaminated soil as a result of large masses of roots. (Emenike et al., 2018; Tomasevic et al., 2005).

3.3 Preventing Heavy Metal Contamination and Potential Use of Trees and Barriers to Prevent Deposition in Green Spaces

Deciduous trees have been found to be efficient at trapping atmospheric deposition of heavy metals attached to soil particles (Tomasevic et al., 2005). They are so effective that they are often indicators of trace metal pollution and certain studies have found 10-15% of leaf surface covered with deposited particles. Leaves with highest accumulation were dependent upon surface roughness and presence of hairs on leaf surfaces (Tomasevic et al., 2005). Most of the dust particles trapped by tree leaves were in smaller than 2um, indicating that pollutants attached to larger dust particles may not be disrupted by tree canopies. Another way in which trees can prevent movement of heavy metals in the soil is through the physical stabilization by tree trunks and roots. Their presence prevents runoff and erosion of soil particles. (Emenike et la., 2018; Tomasevic et al., 2005)   Organic matter from falling leaves also prevents soil movement in a similar way and can help prevent leaching by slowing the inflow of water into the soil (Emenike et al., 2018; Tomasevic et al., 2005).

Although there is research in the field of heavy metal contamination, little research is available on various ways to prevent heavy metal exposure in green spaces, specifically for community gardens in an urban environment. A common recommendation to protect against heavy metal contamination is to ensure the placement of a community garden is between 30-100m from a road, however this becomes less and less feasible with increasing urbanization Oka et al., 2014; Toronto Public Health, 2016).

3.4 Soil Assessment

Due to the potential risks of heavy metal exposure to humans in urban community gardens, soil assessments are important to determine 1) heavy metal levels and 2) potential future exposure to heavy metals. These two objectives inform how an overall assessment should be done to determine safe places to grow vegetables and safe spaces for children to play in. If the previous land use history and traffic exposure resulted in heavy metal deposition, new soil will be imported, typically in the form of a dredged sand mixed with compost (VPB, 2018). However, the risks of heavy metal contamination remain from atmospheric deposition of traffic pollution into the soil. In Vancouver, Oka et al. (2014) found that sites on brownfields, also known as old gas stations and, in high traffic corridors were higher in zinc, copper and lead and posed a potential threat to human health with consumption of food from these places.

Using this information, conducting an assessment for heavy metal concerns in green spaces requires not only looking at current metal contents in soil but also factors that may affect presence of heavy metals in the future, including: location of site, site history, proximity to traffic/industry, density of traffic, and parent material of the soil. Additionally, factors must be assessed that affect the bioavailability of heavy metals as well as physical movement of heavy metals both in the air and the soil.

4.0 Objectives

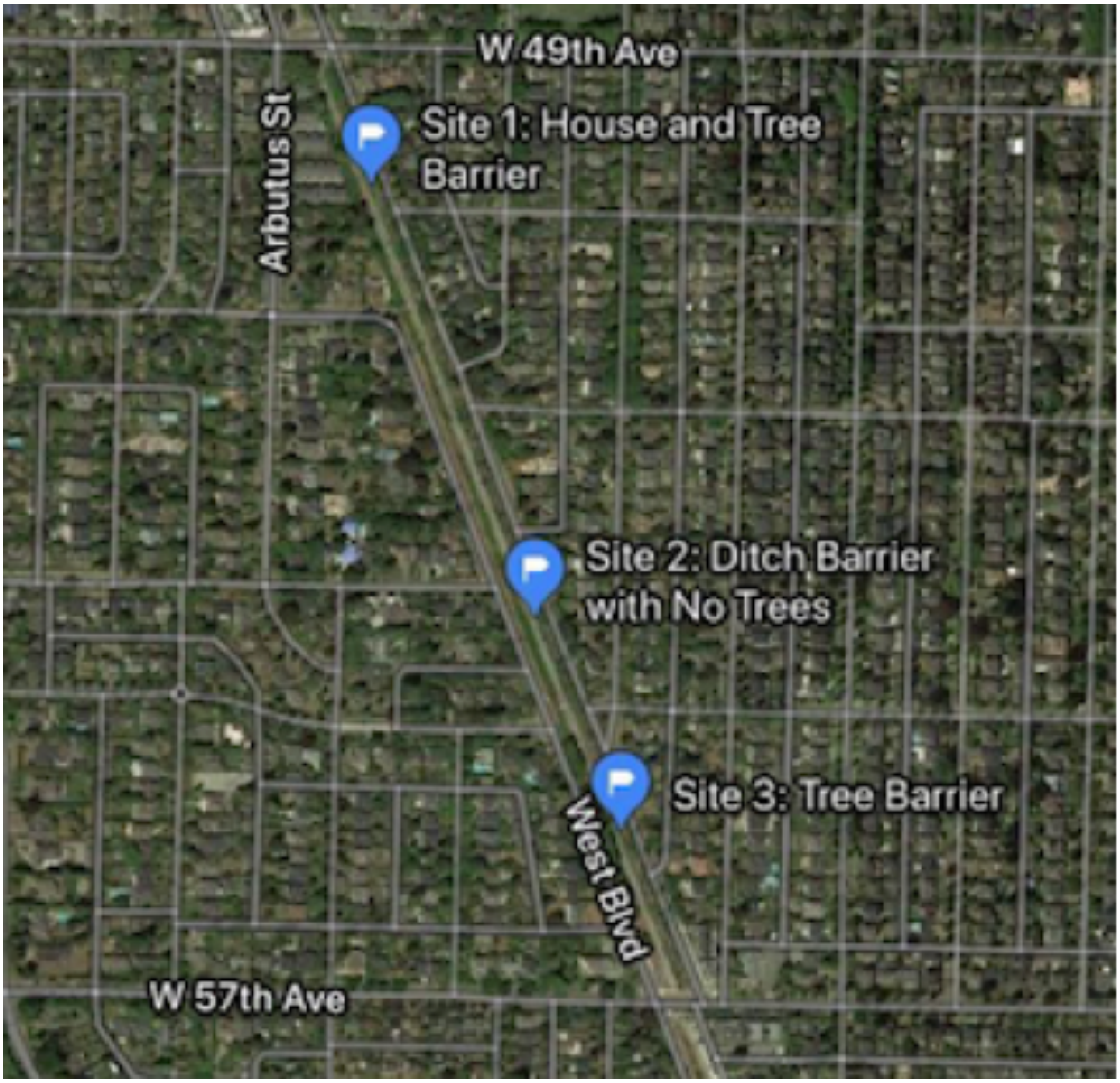
Traffic corridors have been identified as a major source of deposition of heavy metals into soils in Vancouver (Oka et al., 2014; Thomas and Lavkulich, 2015). Therefore, the intent of this project is to do a preliminary, exploratory assessment of a transportation corridor green space. The selected corridor is a small section of the Arbutus Greenway, which is a transportation corridor with a number of narrow greenspaces running adjacent to a bike lane (City of Vancouver, 2018). It runs north/south through the city from 1st avenue to Milton street and there is currently a multi-year plan to diversify the greenspace functions of the corridor (City of Vancouver, 2018). The site has a history of transportation as it was once a railway and is adjacent to a roadway (City of Vancouver, 2018). The site area was selected due to the number of community gardens that exist adjacent to the traffic corridor. The objectives of this assessment are to:

1) Determine available trace metal concentrations along the transportation corridor in both the native soil, imported soil and associated vegetation;
2) Assess potential sources and distribution of heavy metals;
3) Assess whether certain barriers/plants limit the transport of heavy metals;
4) Review the literature for appropriate mitigation techniques when heavy metal contamination is of concern;
5) Make recommendations to public and city officials on how to conduct site assessments for community gardens and safety guidelines to follow and;
6) Identify gaps in research to provide a thorough assessment of risks associated with heavy metal contamination in community gardens;

4.1 Site Description

This site focusses on a section of a new bike transportation corridor that was previously a decommissioned railroad within Vancouver, BC (City of Vancouver, 2018). It has a history of community gardens and has plans for further development as a community resource (City of Vancouver, 2018). The site selected for analysis within the Arbutus Corridor runs between 49th Avenue and 57th Avenue. It was selected as it is relatively uniform in slope, dimensions, green space land uses and exposure to one medium density trafficked road. Community gardens run along the northeast side, a road to the southwest, while a bike lane runs through the middle with grasses and varied vegetation on either side. There is variability in the types of barriers between the greenspaces, community gardens and the road. The sites were selected based on the type of barrier to the roadway to assess the efficacy of these barriers in preventing heavy metal deposition in community gardens.

Map 1.1 of Selected Sites



5.0 Methods

Soil/Leaf Site Sampling

Three sites were selected that were representative of different types of plant and physical barriers along the corridor. Within those three locations, three sites were selected along a transect: one on the south west side of the bike path in the native soil closest to the road, another to the northeast of the bike path in the native soil close to the community garden, and a third in the community garden soil. At each site, three soils samples were taken to a depth of fifteen centimeters within a two-meter radius of the selected point and composited into a single sample for analysis.

Site Name	**Barrier to Road**	**Transect locations for soil samples**
Site 1	Trees and houses	1-Closest to houses on Northwest side 2-Native soil by community Garden 3-Community Garden soil
Site 2	Ditch with no trees	1-Closest to road before the ditch 2-Native soil by community garden site 3-Community garden soil
Site 3	Deciduous tree barrier before road	1-Soils closest to road after the trees 2-Native soil by community garden site 3-Community garden soil.

Table 1.1: Sites and Locations for Soil Sampling

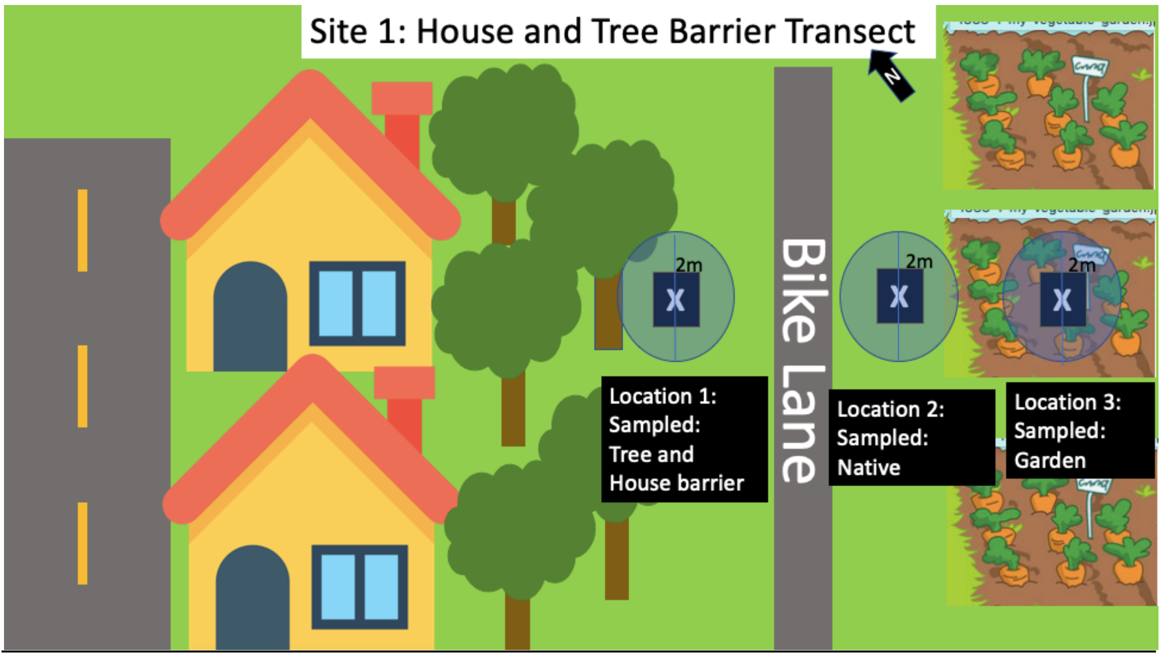


Figure 1.1 Sampling Design of Site 1

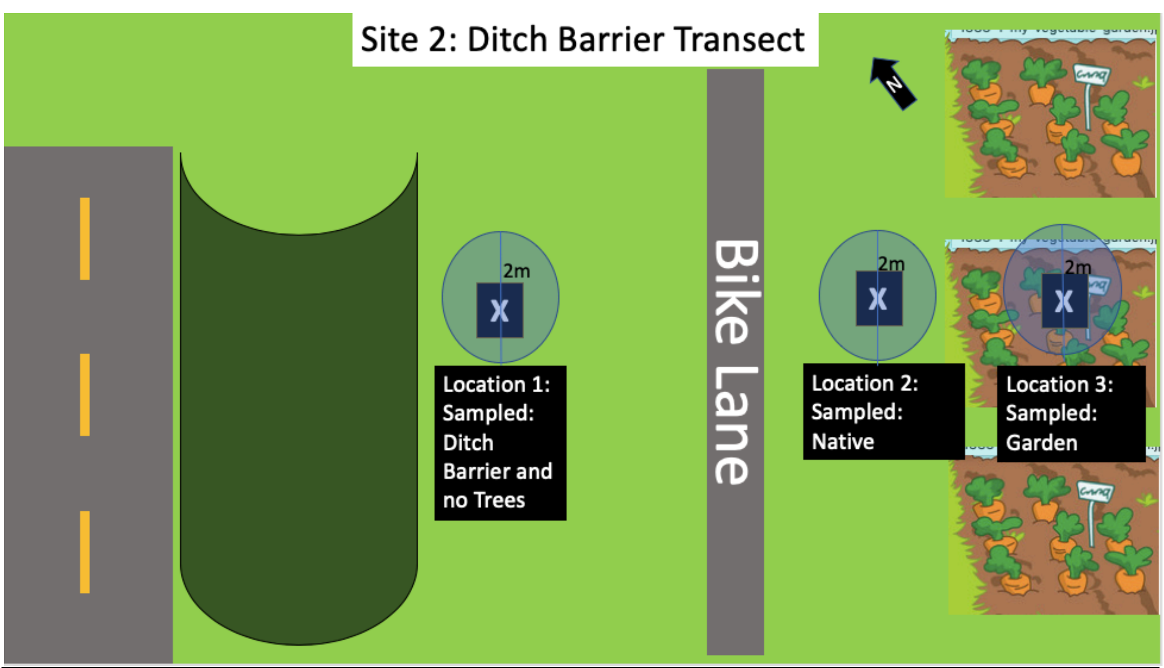


Figure 1.2 Sampling Design of Site 2

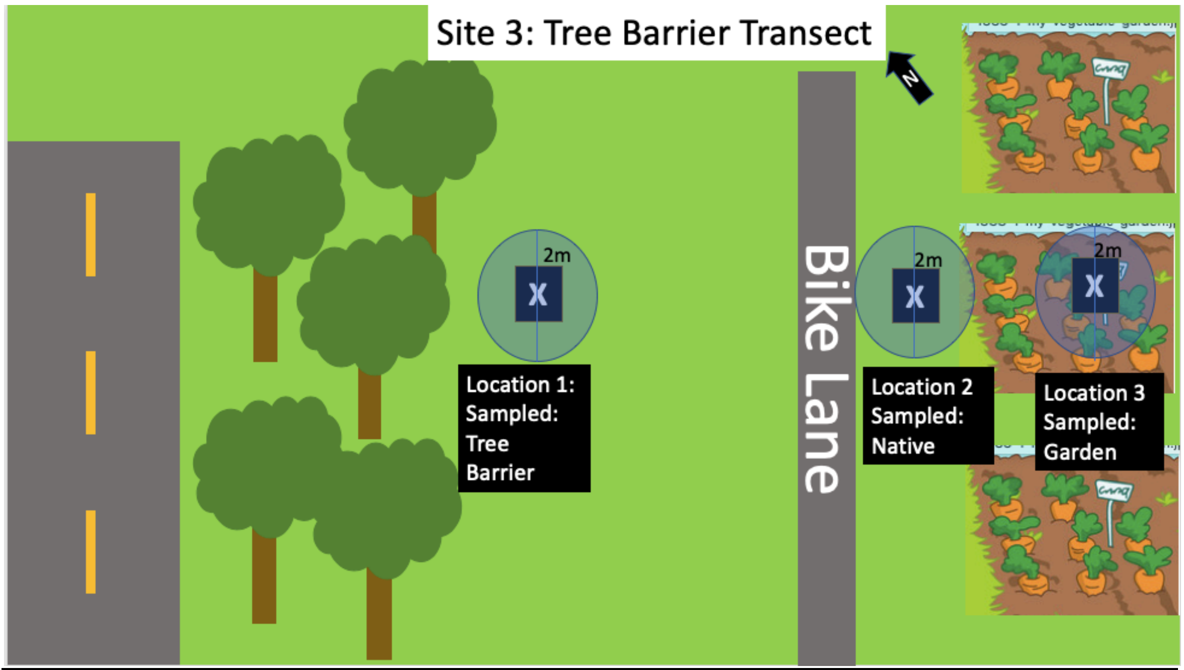


Figure 1.3 Sampling Design of Site 3

Where available, clover samples were taken for tissue analysis to represent plant accumulation of heavy metals. Five to seven leaves from a maple tree were taken in the transects where trees leaves were present to analyze accumulation in trees.

Lab Analysis

Soil Analysis

Preparation

All soil samples were mixed thoroughly and air dried for 48 hours and sieved to 2mm. Any large grass particles or sticks were removed.

Analysis

1) **pH:** Using the soil:water measurement nd 0.01 M $CaCl_2$ procedure

   (Hendershot et al., 1993).

2) **Ash content and organic matter content:** Using the loss on ignition procedure (Ball, 1964)

3) **Extraction of labile metal from solid media by dilute hydrochloric acid:** Procedure by: Sutherland and Tack, (2008). This represents the approximate labile or available metal fraction in the soil (Sutherland and Tack, 2008). Samples were analyzed using inductively coupled plasma atomic emission spectrometer for: Cu, Cr, Co, Pb, Ni, Mn, Cd and Zn

Leaf and Plant Tissue Analysis

Preparation

Clover Analysis: Samples were dried at 65°C in an oven. Roots and shoots were separated. The shoot and leaf mass were crushed and mixed and one gram of material was weighed out into crucibles. They were then placed in an oven for fifteen hours at 100°C.

Maple Analysis: Leaves were rinsed in a 0.1 M dilution of acetic acid solution followed by distilled water. They were then put in an oven for twelve hours at 65°C. Samples were crushed and mixed, and one gram of material was weighed out into crucibles and put into the oven for fifteen hours at 100°C.

Analysis

All vegetation samples underwent total metal analysis by aqua regia procedure described by Cheng and Ma (2001). They were then analyzed using inductively coupled plasma atomic emission spectrometry for: Cu, Cr, Co, Pb, Ni, Mn, Cd and Zn

Literature Review of Phytoremediation Mitigation Strategies

Review the literature for current phytoremediation strategies used for heavy metal contamination globally, and research Vancouver specific examples.

6.0 Results

6.1 Total Available Metal Content in the Soil:

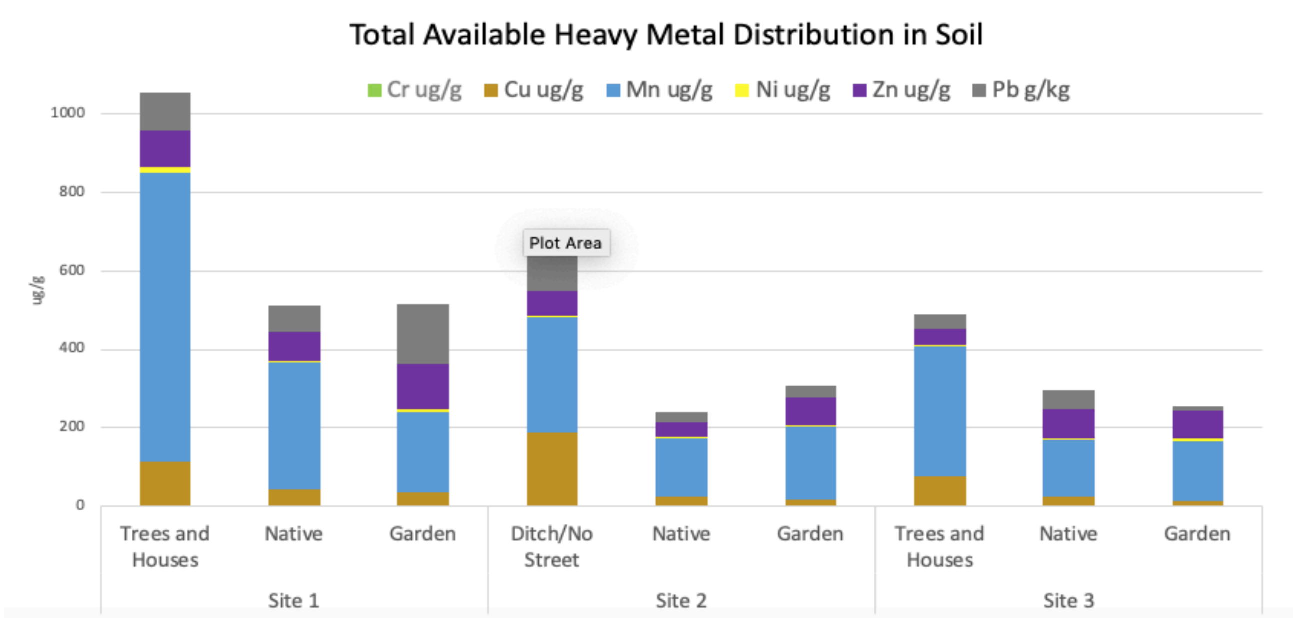


Figure 6.1: Total available metal content and distribution throughout the three sites and transect locations

There was little to no found concentration of cadmium or cobalt, therefore they are not presented in the graph. As seen in figure 5.1, heavy metal concentrations are highest in the locations closest to the road at all three sites. Lower concentrations are found in both the native soil near the community garden and in the community garden soil. Manganese appears to be the dominant heavy metal in the soil, followed by copper and depending on the site, either lead or zinc. Nickel and chromium appear to have minimal contribution to soil heavy metals with little to no difference between sites.

6.2 Manganese Content in the Soil

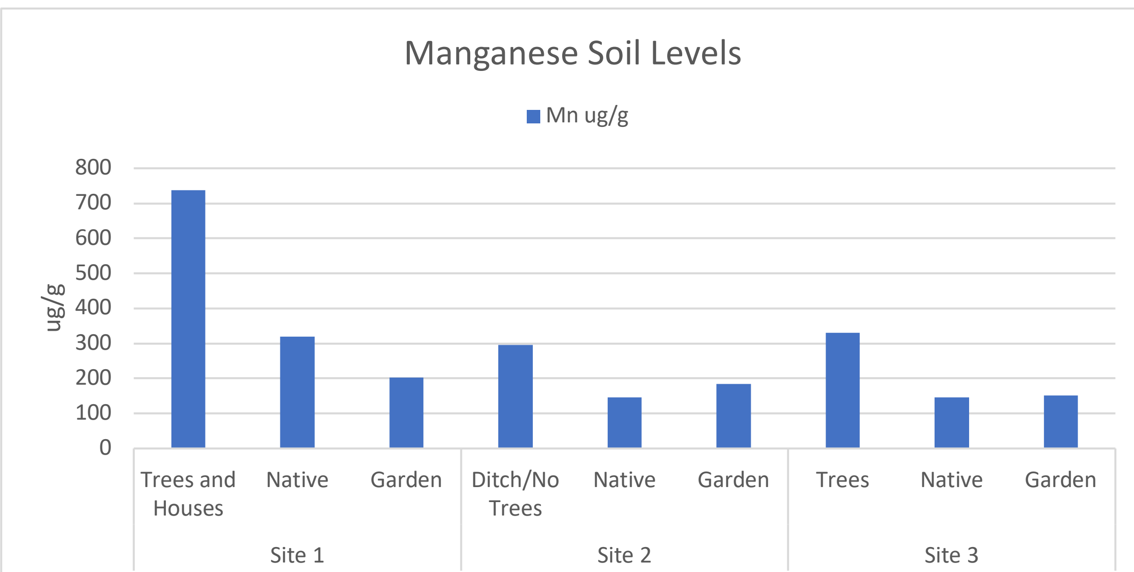


Figure 6.2 Manganese concentration distribution in the soil

The highest manganese concentrations are at Site 1 (figure 5.2), in the location closest to the road. This site had barriers of both trees and houses. The sampling locations closest to the road, that are also adjacent to the different barriers, at all three sites appear to have slightly higher concentrations of manganese than the native and garden sampling locations.

There are no noticeable differences in the concentrations of manganese between the native soil and the garden sample locations. The parent materials in the Fraser Valley have background levels of manganese ranging between 20-920 or ug/ e, indicating that the variability here could just be from variations in the inherent material (Luttmerding, 1981).

6.3 Lead Content in the Soil

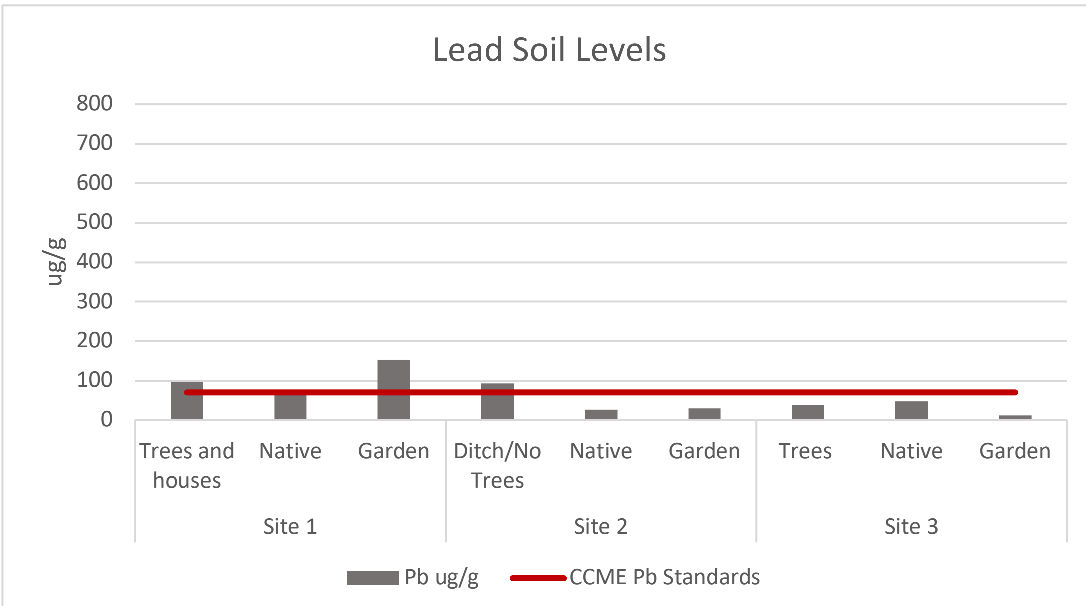


Figure 6.3 Lead concentration distribution in the soil and CCME standards for thresholds of total lead content allowed in agricultural soils. CCME for lead is 70 ug/g(CCME, 2017)

The lead concentrations were highest in Site 1, with the highest concentrations found in the garden sampled location. The Canadian Council of Ministers of the Environment (CCME) created guidelines for maximum thresholds of total metal concentrations that should be present in agricultural soils (CCME, 2017). For lead, soils should not have total lead concentrations above 70 ppm or ug/g (CCME, 2017). In the garden soils of site 1, lead levels are 150 ug/g, which is over double the CCCME recommended level. More concerningly, is that the analysis done in this study was only on available lead content, indicating that total lead content could be even higher than the present values. Oka et al. (2014), found the ratios of total metals to available metals for lead in Vancouver soils ranged between 3-15 (total metals/available metal concentrations) in community garden/urban farming sites. This indicates that that total lead levels at this site could be between three to fifteen times higher than the available content (Oka et al.,2014). The barrier sample locations, in both Site 1 and Site 2 also surpass the CCME guidelines with lead concentrations of 95 ppm and 90 ppm respectively. There appear to be no trends that correlate lead levels, distance from traffic, imported/native soil or the effects of barriers.

6.4 Copper Content in the Soil

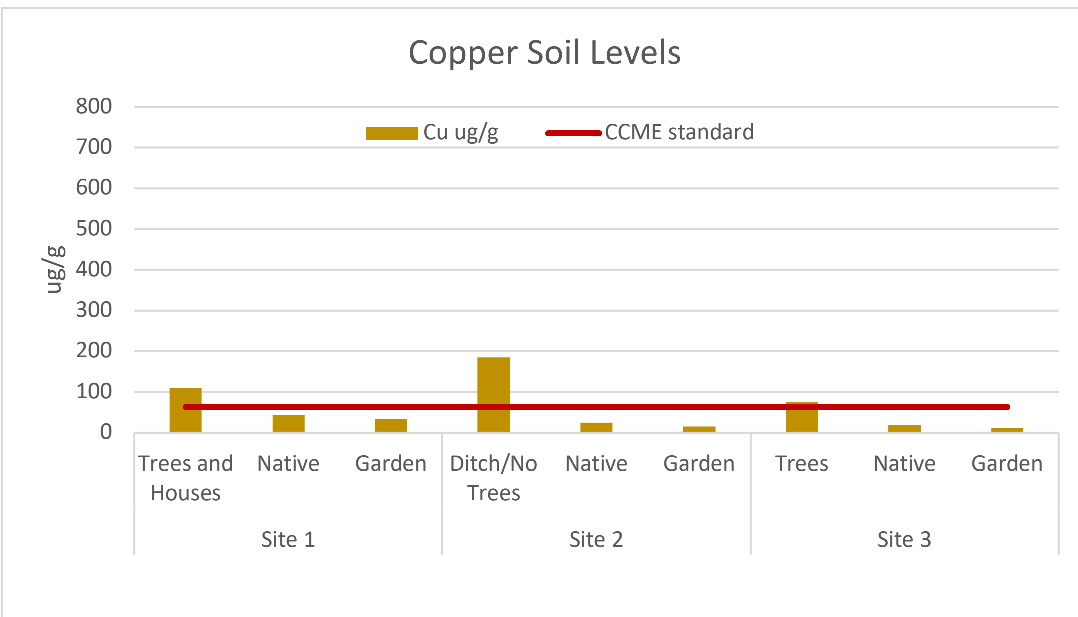


Figure 6.4 Copper concentration distribution in the soil and CCME standards for thresholds of total copper content allowed in agricultural soils. CCME for copper is 62 ug/g

The CCME guidelines (2017) describe threshold safe levels for copper to be 62 ug/g for agricultural soils (CCME, 2017). These were exceeded in all sites at the sample location closest to the road. Samples from both the native and garden locations were significantly lower and are further from the road. As with lead, the guidelines provided by the CCME represent total copper threshold levels and not only the available fraction. Although the native and garden sample locations had copper levels below the CCME guidelines, the ratio between available and total copper concentrations can vary between 2-12 times greater total metal concentrations compared to the analyzed available copper metal concentration (Oka et al., 2014). Background levels for copper range between 20-50 ug/g which could contribute to some of the levels found in the native soils (Luttmerding, 1981).

6.5 Zinc Content in the Soil

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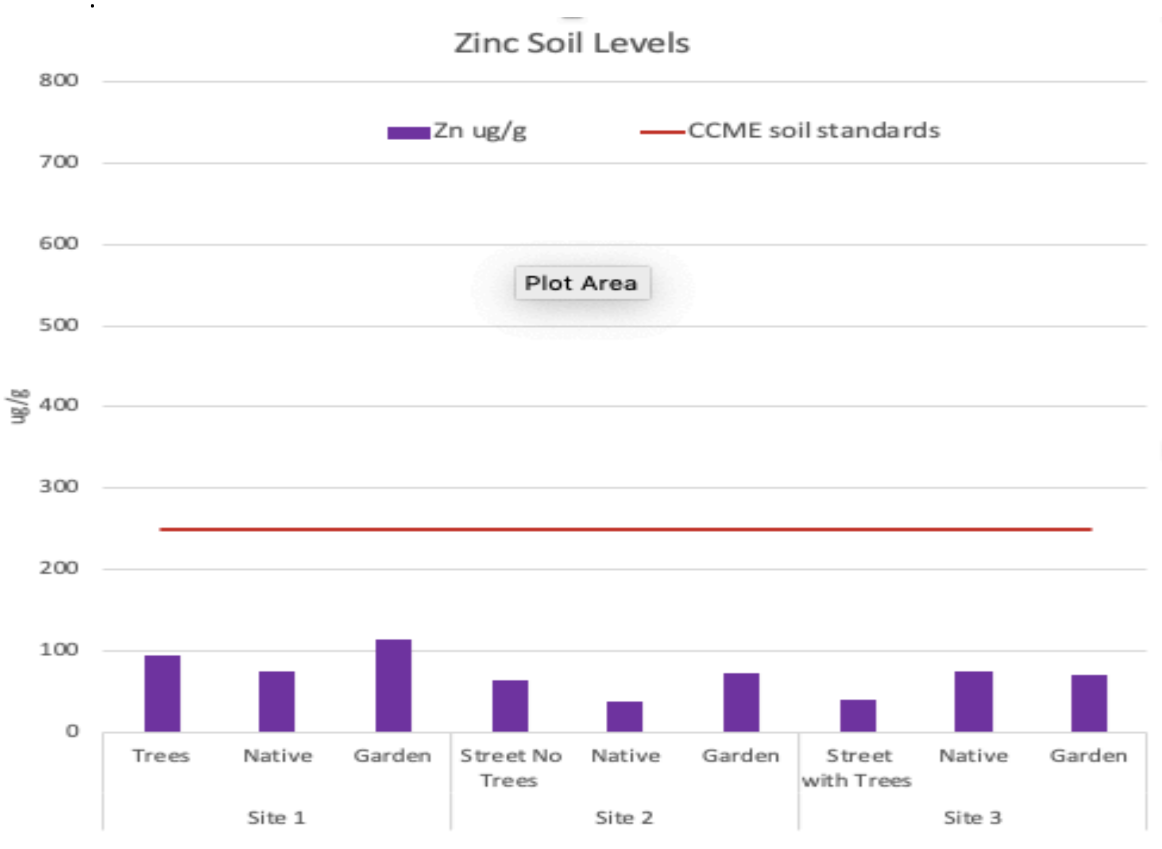

Figure 6.5 Zinc concentration distribution in the soil and CCME standards for thresholds of total zinc content allowed in agricultural soils. CCME for zinc is 250 ppm

The zinc levels are variable, but slightly higher in the sampling locations closest to the road in the barrier locations. However, they are all significantly below the CCME thresholds of 250 ug/g of zinc (2017). Oka et al. (2014), found ratios of total metals/available metals for zinc to be between 2 and 4. This indicates that the total metal content could be between 2 to 4 times higher than the available metal concentrations that were analyzed. Inherent metal concentrations in the Fraser Valley range from 50-150 ug/g therefore the zinc content could be due to background levels (Luttmerding et al., 1981).

6.6 Vegetation Uptake of Heavy Metals

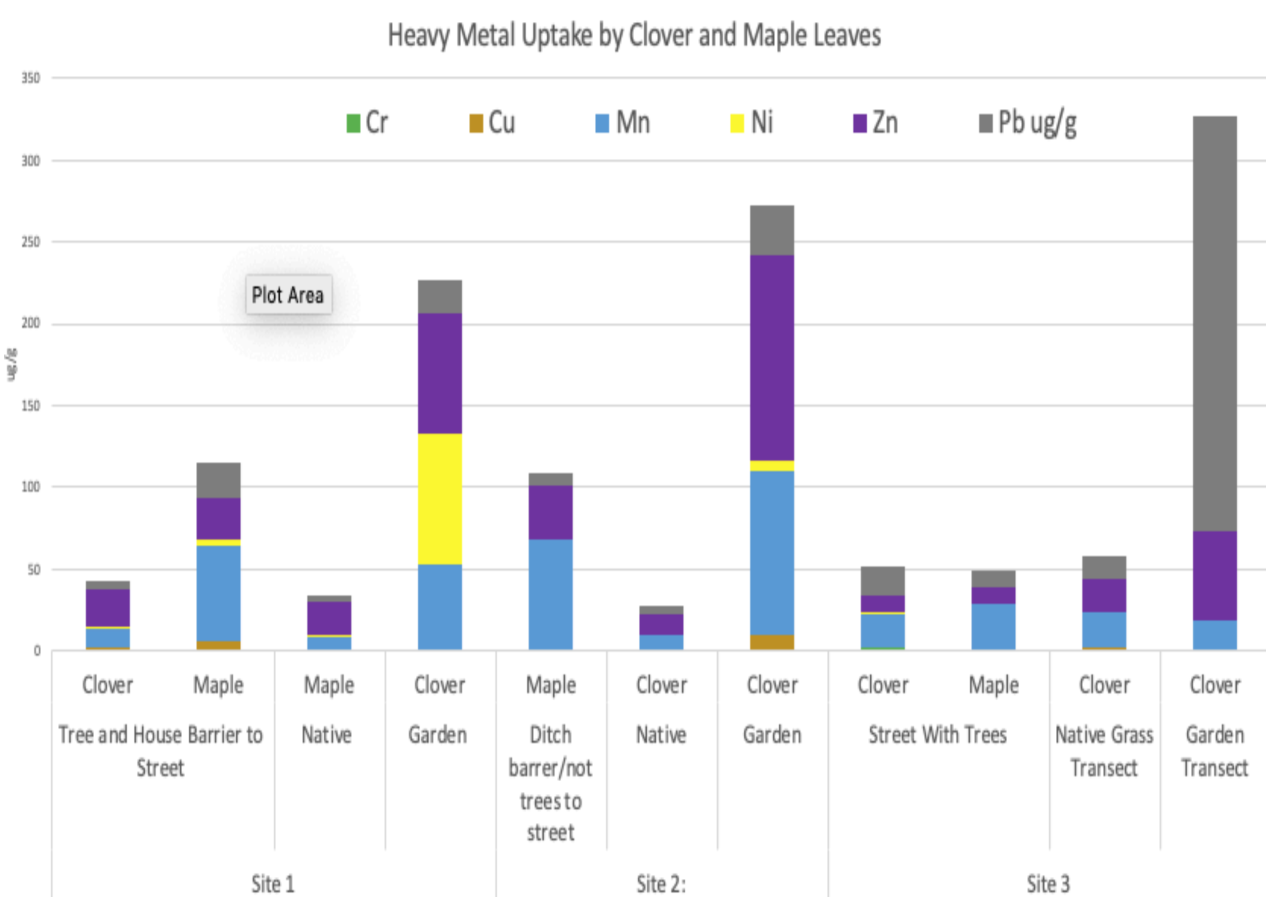

Figure 6.6 Vegetation (maple and clover) uptake of heavy metals

Although the graph in figure 6.6 shows great variability, it is evident that there is uptake of heavy metals by the vegetation, especially lead, zinc and manganese. The highest heavy metal accumulation in maple leaves occurs in Site 1 at the tree and house barrier sampling locations, which is also the closest to the road at that site. The clover, a hardy perennial plant, that sits low to the ground was found in most of the sites. It had varied heavy metal uptake in each site and transect. No visible trends occurred within transects or sites for either the maple and clover plants, but uptake did occur at all sites and locations - including the garden locations. This is important as it indicates the potential for heavy metal accumulation in vegetable crops, resulting in human consumption. Additionally, the trees have the potential to be phytoextractors of heavy metals (clover biomass is too small), provided research is conducted on what happens to the metals with seasonal leaf fall.

5.7 Correlations between pH and Organic Matter:

There were no trends found between the organic matter content and any of the metals or the pH levels and metal availability. Metals are often released when pH is below 5.5 (Thomas and Lavkulich, 2015) and none of these soil samples had pH values that were below 5.5. This might explain why there is no correlation with metal availability and pH. Due to the variability of metal concentrations and organic matter, no extrapolations can be made on whether they contributes to the presence or availability of heavy metals.

5.8 Review of Possible Phytoremediation techniques

Phytoremediation has been used worldwide in different ways to remove pollutants. Emenike et al. (2018), identified 400 species globally either in wetlands or terrestrial environments that were effective at phytoremediation. Many organic pollutants can be completely transformed and degraded by plants, however, heavy metals can only be stabilized or extracted as there are no natural mechanisms for biodegradation (Padmavathiamma and Li, 2009). The stabilization of heavy metals by plants is known as phytostabilization, whereby plants prevent the movement of heavy metals in the soil through roots stabilizing soil and thus preventing erosion, leaching and runoff. Another form of phytostabilization that is possible, is through accumulation of heavy metals in plant roots (Emenike et al., 2018 Padmavathiamma and Li,., 2009). The extraction of heavy metals by plants is known as phytoextraction, which is the accumulation of heavy metals into plant tissue, thus eliminating them from the soil (Emenike et al., 2018). Plant species also differ in where heavy metals accumulate within plant tissue, with certain species having a root dominance in heavy metals and others accumulating metals to their shoots (Tošić et al., 2016). Kabata-Pendias (2011) found that plants that retained heavy metals in their root tissue often had higher plant survival rates, thus being more tolerant. However, Tošić et al. (2016), found that if a plant is able to tolerate heavy metals in their shoot mass they are able to accumulate between 100-1000 times more heavy metals than other plants, and are known as hyperaccumulators.

The process of phytoextraction begins with root system uptake, translocation, bioaccumulation and storage of the metal in plant parts (Emenike et al., 2018). Often plants with high biomass are good hyperaccumulators, such as willow tree species *Salix spp.* (Emenike et al., 2018). Certain plants are better at accumulating certain metals than others. For example, a study in Taiwan found that narrowleaf plantain, cosmos, zinnias and verbena all had high cadmium adsorption rates (Chen and Lee, 1997). Paz-Alberto and Sigua (2013) found that most brassicas a such as Indian mustard and flowering kale, are effective hyperaccumulators, provided they are not ingested. However, no information in these studies was provided on what happens to heavy metals when these plants die and return to the soil as organic matter. Although Kessler (2013) states that organic matter will chelate heavy metals, which would convert them to a plant unavailable form. Given the colder climate of Vancouver, especially in the winter months (Pott and Turpin, 1998), understanding organic matter transformation of heavy metals is important as many plants do not overwinter. Additionally, heavy metal accumulation can be dependent on climate and soil type making regional studies of plants and their uptake performance important (Kabata-Pendias, 2011).

There has been one study that has looked at the phytoremediation potential of plants in Vancouver for heavy metals associated with traffic. Padmavathiamma and Li (2009) found that perennial rye grass (*Lolium perenne)* was effective at phytostabilizing copper and lead, creeping red fescue *Festuca rubra* was effective at phytostabilizing copper and Kentucky bluegrass (*Poa pratensis)* was able to phytostabilize zinc. The phytostabilization mechanism for all of these plant species was a retention of heavy metals in their plant roots (Padmavathiamma and Li, 2009). They also found that sunflowers, *Helianthus annus* were able to phytoextract significant levels of lead and zinc. However, as these are annual species it is unknown what heavy metals will become available when these metals are returned to the soil in organic matter at plant death (Padmavathiamma and Li, 2009). None of these species were considered hyperaccumulators: plants able to accumulate metals greater than 1% of their biomass, signifying they were effective only in moderate levels of heavy metal contamination (Padmavathiamma and Li, 2009). Hyperaccumulators are often associated with wetland species, as wetlands serve as sinks for heavy metals, plants have evolved to be able to withstand higher concentrations (Emenike et al., 2018).

7.0 *Discussion:*

7.1 Were Heavy Metals in the Sampled Community Gardens at Safe Concentrations?

Generally, except for site 1 garden's lead content, all garden sites levels of heavy metals were below the CCME guidelines for safe vegetable production (2017). In studies done in numerous cities in Australia and the United States, lead has been identified as the metal typically of the greatest concern, due to its persistence, toxicity effects and widespread use in paints and gasoline up until the 1970s (Houillon et al., 2017; New York State Department of Health, 2016; Kessler, 2013) Determined thresholds for safe levels of metals in soils vary greatly internationally. The Canadian threshold of 70 ug/g created by the CCME is significantly lower than other international standards for lead contamination. The EU has a threshold level of 100 ug/g and many states in the US have safe threshold levels as high as 400 ug/g (Houilon et al., 2017). Therefore, it is difficult to determine if these lead levels are of a concern for human health in the community garden site, however they are above the thresholds set in Canada.

7.2 Correlations Between: Heavy Metals, Traffic and Distance from Road

The main trend visible from the data that is seen in the levels of copper and manganese and total concentrations of metals, demonstrates that metal content was highest at the barrier locations, which are closest to the road. This reflects the idea that heavy metal content is concentrated closest to the road. Therefore, the major source of the available heavy metals, is likely coming from vehicles in the traffic corridor. The largest concentrations of metals found in the soils and vegetation were: lead, manganese, copper and zinc. This corresponds to previous research that shows that zinc, copper and lead/manganese (when it was in fuels) were the most common heavy metals released from automobiles In Vancouver (Thomas and Lavkulich, 2015; Li et al., 2009) and in other developed countries such as Australia and the United States (Houillon et al., 2017; New York State Department of Health, 2016; Kessler, 2013; Laidlaw et al., 2018). In previous studies done in the Australia and Canada, there was no difference found between manganese levels and distance from roads (Rouillon et al., 2017). Although no Canadian thresholds exist for manganese in agricultural soils, in Australia, the threshold was 3000ug/g (Laidlaw et al., 2018). This is significantly higher than any level of available manganese found in the soils in this study. Copper and zinc have been found in the Huisson et et al., (2017) and Wuana and Okiemen (2011) study to be correlated with traffic emissions with greater concentrations closest to roadways. As previously stated, automobiles release these metals in: the combustion process, brake disk and lining wear and rubber tire wear (Hamzeh et al., 2011; Laidlaw et al., 2011). Other international research has identified paints and pesticides as other sources of heavy metal contamination in urban soils (Szolnoki et al., 2013; Gulson et al., 1995)..Due to the low levels of heavy metals found in the native soil further from the road, it is unlikely that the railroad contributed significantly to available metal content.

Understanding that traffic is likely the major contributor to heavy metals in this area highlights the importance of assessing heavy metal exposure when planning community gardens. Based on the results of this assessment as well as previous literature, it is important to ensure that a sufficient distance is given between the road and the garden or play area (as children have dermal contact with soils). The variability in data and the high metal content in site 1, which had both the trees and houses as barriers makes it difficult to determine what kind of barrier is effective for heavy metals. Information was lacking on traffic densities in the area and the higher concentrations found in this site could be attributed to the perceivably higher number of intersections close to 49th street. The higher concentrations could also be a result of heavy metal deposition on the rooftops which then dripped onto the soils as a result of rainfall. Additionally, the materials used in the houses can have metal components, such as galvanized rain gutters that deposited heavy metals into the soils with wear. To create a better understanding of what a safe distance is from a road to a community garden, more research is required in creating correlations between wind, weather and traffic densities with heavy metals. Additionally, research into the potential of houses contributing heavy metals to the soil should be carried out, which could pose a concern for domestic vegetable gardening.

6.2 Phytoremediation/Stabilization Barriers

It is unclear whether the barriers studied have an effect on preventing heavy metal transfer into soils. Whereas distance from road appeared to have a significant impact on heavy metal concentrations in the soil. It is possible that the vegetative ditch is just as effective as the trees for preventing travelling atmospheric deposition or runoff. More rigorous research into the effectiveness of barriers would be beneficial to determine alternative ways to prevent heavy metals contamination in a way that allows for safe diversification of green spaces without requiring long distances from roads. Another barrier not explored but suggested by Kessler et al. (2013), is the use of raised beds to prevent heavy metal contamination associated with contaminated soil particles that could be transported through erosion and runoff mechanisms. Moreover, there is global research on phytoremediation techniques, but research relating to Vancouver soils and the capacity of plants to act as phytoremediation agents would be beneficial to help discover ways to prevent buildup of heavy metals in soils. Currently, one study has identified that for Vancouver, planting a combination of Kentucky Bluegrass (*Poa pratensis),* Creeping Red Fescue *(Festuca rubra)* and Perennial Rye Grass *Lolium perenne* were effective together at phytostabilizing heavy metals associated with traffic deposition (Padmavathiamma et al., 2009).

6.3 Investigation of Imported Soils

Soils are often imported for community gardens to prevent heavy metal contamination associated with the previous land use. However, as indicated by the high content of lead in the first site at the garden location, it is imperative that an analysis of the imported soil is given to avoid contamination. Moreover, as lead is the least mobile of the heavy metals, the various barriers may not have been present when lead would have been emitted pre 1975 traffic use (Thomas and Lavkulich, 2015).

6.4 Research in Plant Uptake of Heavy Metals

The data is extremely variable for plant uptake of metals by maple trees and clover but what is evident is that heavy metals are being taken up by vegetation. However, there was a lack of correlation between soil “available metals” based on the hydrochloric acid extraction analysis and the metal content found in the vegetation. This indicates the need for further assessments/research to understand uptake mechanisms of heavy metals by plants. As well as designing tests and correlations between the assessment tools for plant available metal content in soils, and what is actually taken up by plants.

7.0 Conclusions:

- With the exception of lead in the first garden site, the heavy metals in the soils used for community gardening in the study site had concentrations low enough to be considered safe by the CCME guidelines for human consumption of vegetables
- This assessment identified manganese, zinc, lead and copper as the main heavy metals released at the study site, likely from as a result of traffic. This is similar to the previous studies conducted in Vancouver by Oka et al., (2014) and Thomas and Lavkulich, (2015);
- Vancouverites using greenspaces, need to be aware of the role traffic can have on heavy metal contamination in soils used for growing food and playgrounds;
- If contamination is a concern, avoid root crops and leafy greens vegetables even if they are washed
- More data and research is required on local conditions and how weather and local traffic data could effect heavy metal deposition and accumulation in soils
- More research should be conducted on local plant species that can contribute to phytoremediation and the role trees, barriers and ditches can play in preventing heavy metal deposition in gardens

8.0 Recommendations to Community Gardeners and City Planners

- Soils should be tested before planning a garden as well as every few years as heavy metals accumulate, and traffic densities increase;
- Prior to developing a community garden or playground, test the soil, but also consider the parent material of the soil, site history, surrounding activities, traffic and urban densities, weather and wind patterns, type of soil (including texture, organic matter and pH;
- When importing topsoil, ensure it is tested before purchase and planting vegetables
- After an initial assessment, periodically (every few years) check the levels of heavy metals in vegetables and soil in your community garden or playground

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10. Appendix:

Cadmium Content in Soils ug/g

Site Number	Transect	Cd ug/g
Site 1	Trees and house barrier to street	0.76916667
	Native	0.47733333
	Garden	0.54733333
Site 2	Ditch barrier/no trees to street	0.476
	Native	0.207
	Garden	0.29316667
Site 3	Tree Barrier to street	0.42833333
	Native	0.35983333
	Garden	0.39633333

Cobalt Content in Soils ug/g

Site Number	Transect	Co ug/g
Site 1	Trees and house barrier to street	0.8605
	Native	0.66633333
	Garden	1.031
Site 2	Ditch barrier/no trees to street	0.58033333
	Native	1.1325
	Garden	1.0705
Site 3	Tree Barrier to street	0.90066667
	Native	1.047
	Garden	0.8695

Chromium Content in Soils ug/g

Site Number	Transect	Cr ug/g
Site 1	Trees and house barrier to street	3.87433333
	Native	2.25916667
	Garden	2.69616667
Site 2	Ditch barrier/no trees to street	2.08083333
	Native	1.89966665
	Garden	2.34633333
Site 3	Tree Barrier to street	2.4605
	Native	4.67933333
	Garden	2.1775

Lead Content in Soils ug/g

Site Number	Transect	Pb ug/g
Site 1	Trees and house barrier	95.3166667
	Native	67.1166667
	Garden	152.966667
Site 2	Ditch barrier/no trees	92.7166667
	Native	26.2533334
	Garden	29.79
Site 3	Tree Barrier	37.94
	Native	46.65
	Garden	11.4
CCME Threshold		70

Copper Content in Soils ug/g

Site Number	Transect	Cu ug/g
Site 1	Trees and house barrier	109.683333
	Native	43.2066667
	Garden	34.2083333
Site 2	Ditch barrier/no trees	184.683333
	Native	24.6866667
	Garden	15.5016667
Site 3	Tree Barrier	75.3166667
	Native	18.9583333
	Garden	11.965
	CCME	63

Manganese Content in Soils ug/g

Site Number	Transect	Mn ug/g
Site 1	Trees and house barrier	737.5
	Native	319.65
	Garden	202.35
Site 2	Ditch barrier/no trees	294.8
	Native	146.4
	Garden	184.1
Site 3	Tree Barrier	329.975
	Native	146.275
	Garden	151.575

Nickel Content in Soils ug/g

Site Number	Transect	Ni ug/g
Site 1	Trees and house barrier	12.95
	Native	3.55
	Garden	7.95
Site 2	Ditch barrier/no trees	4.05
	Native	3.34975
	Garden	3.55
Site 3	Tree Barrier	3.8835
	Native	3.833
	Garden	6.4825
CCME Threshold		45

Zinc Content in Soils ug/g

Site Number	Transect	Zn ug/g
Site 1	Trees and house barrier	93.9
	Native	75.65
	Garden	115.05
Site 2	Ditch barrier/no trees	64.2
	Native	37.85
	Garden	71.75
Site 3	Tree Barrier	39.05
	Native	74.65
	Garden	71.2
CCME Threshold		250

pH Levels of Soils Sampled

Site Number	Transect	pH Soil: Water	pH CaCl2 0.0067 M
Site 1	Trees and house barrier to street	5.6	4.98
	Native	6.47	5.95
	Garden	6.88	6.75
Site 2	Ditch barrier/no trees to street	6.12	5.21
	Native	6.18	5.64
	Garden	7.07	6.86
Site 3	Tree Barrier to street	6.01	5.38
	Native	6.86	6.34
	Garden	7.87	7.48

Organic Matter Content of Soils Sampled

Site Number	Transect	% Organic Matter
Site 1	Trees and house barrier to street	15.55555556
	Native	14.85714286
	Garden	38.63636364
Site 2	Ditch barrier/no trees to street	22
	Native	17.64705882
	Garden	33.33333333
Site 3	Tree Barrier to street	14.97005988
	Native	15.38461538
	Garden	30.05181347

Cadmium Content in Vegetation of Maple and Clover

Site Number	Transect		Cd ug/g
Site 1	Trees and house barrier to street	Clover	0
		Maple	0
	Native	Maple	0
	Garden	Clover	0
Site 2:	Ditch barrier/no trees to street	Maple	0
	Native	Clover	0
	Garden	Clover	0
Site 3	Tree barriers to street	Clover	0
		Maple	0
	Native	Clover	0
	Garden	Clover	0

Cobalt Content in Vegetation of Maple and Clover

Site Number	**Transect**		**Co ug/g**
Site 1	Trees and house barrier to street	Clover	0
		Maple	0
	Native	Maple	0
	Garden	Clover	0
Site 2:	Ditch barrier/no trees to street	Maple	0
	Native	Clover	0
	Garden	Clover	0
Site 3	Tree barriers to street	Clover	0
		Maple	0
	Native	Clover	0
	Garden	Clover	0

Chromium Content in Vegetation of Maple and Clover

Site Number	**Transect**		**Cr ug/g**
Site 1	Trees and house barrier to street	Clover	0
		Maple	0
	Native	Maple	0
	Garden	Clover	0
Site 2:	Ditch barrier/no trees to street	Maple	0
	Native	Clover	0
	Garden	Clover	0
Site 3	Tree barriers to street	Clover	2.312139
		Maple	0
	Native	Clover	0
	Garden	Clover	0

Copper Content in Vegetation of Maple and Clover

Site Number	Transect		Cu ug/g
Site 1	Trees and house barrier to street	Clover	2.02702703
		Maple	6.14035088
	Native	Maple	0
	Garden	Clover	0
Site 2:	Ditch barrier/no trees to street	Maple	1.5625
	Native	Clover	0
	Garden	Clover	10.169492
Site 3	Tree barriers to street	Clover	0
		Maple	0
	Native	Clover	1.986755
	Garden	Clover	0

Manganese Content in Vegetation of Maple and Clover

Site Number	Transect		Mn ug/g
Site 1	Trees and house barrier to street	Clover	11.4864865
		Maple	58.7719298
	Native	Maple	8.18181818
	Garden	Clover	53.3333333
Site 2:	Ditch barrier/no trees to street	Maple	67.1875
	Native	Clover	9.79020979
	Garden	Clover	100
Site 3	Tree barriers to street	Clover	20.809249
		Maple	28.440367
	Native	Clover	21.192053
	Garden	Clover	18.181818

Nickel Content in Vegetation of Maple and Clover

Site Number	**Transect**		**Ni ug/g**
Site 1	Trees and house barrier to street	Clover	2.02702703
		Maple	3.50877193
	Native	Maple	1.81818182
	Garden	Clover	80
Site 2:	Ditch barrier/no trees to street	Maple	0
	Native	Clover	0
	Garden	Clover	6.779661
Site 3	Tree barriers to street	Clover	1.156069
		Maple	0
	Native	Clover	0
	Garden	Clover	0

Zinc Content in Vegetation of Maple and Clover

Site Number	**Transect**		**Zn ug/g**
Site 1	Trees and house barrier to street	Clover	21.6216216
		Maple	24.5614035
	Native	Maple	20
	Garden	Clover	73.3333333
Site 2:	Ditch barrier/no trees to street	Maple	32.03125
	Native	Clover	13.286713
	Garden	Clover	125.423729
Site 3	Tree barriers to street	Clover	9.82659
		Maple	11.009174
	Native	Clover	21.192053
	Garden	Clover	54.545455

Lead Content in Vegetation of Maple and Clover

Site Number	**Transect**		**Pb ug/g**
Site 1	Trees and house barrier to street	Clover	5.40540541
		Maple	22.8070175
	Native	Maple	4.54545455
	Garden	Clover	20
Site 2:	Ditch barrier/no trees to street	Maple	7.8125
	Native	Clover	4.195804
	Garden	Clover	30.508475
Site 3	Tree barriers to street	Clover	17.34104
		Maple	10.091743
	Native	Clover	13.907285
	Garden	Clover	254.545455