MONITORING THE SOIL FOR CONTAMINANTS AT AN INDUSTRIAL PROPERTY IN TORONTO, ONTARIO, CANADA

by

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Bachelor of Environmental Studies (Honours), York University, 2008

A Professional Project Paper presented to Ryerson University

in partial fulfillment of the requirement for the degree of

Master of Applied Science

in the Program of

Environmental Applied Science and Management

Toronto, Ontario, Canada, 2018

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ABSTRACT

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Master of Applied Science, 2018

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Environmental Applied Science and Management

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The focus of this project was to determine whether the soil at an industrial facility was contaminated above background concentrations in Ontario, and whether there was an unacceptable level of risk to the health of humans and the environment. The sampling plan, analysis and data interpretation were developed using guiding documents from the Ministry of the Environment and Climate Change, the Canadian Council of the Ministers of the Environment, and the United States Environmental Protection Agency. An emphasis was placed upon quality control, and a rigorous protocol for sub-sampling, to produce representative sub-samples for analysis. The results revealed that the soil at the site was within the range of background values for Ontario, and there was not an unacceptable level of risk to the health of humans and the environment for the elements analyzed.

ACKNOWLEDGEMENTS

I extend my gratitude to the following people for their help and support in the development and completion of my project paper:

Dr. Ana Pejović-Milić, for your willingness to supervise me as a part-time student, and for allowing me to pursue a project that has advanced my knowledge in my chosen career path; Dr. Michal Bardecki and Dr. Lynda McCarthy for your helpful insights during the creation and development of this project; the company for allowing me to perform this project at their facility; and the faculty of Environmental and Applied Science and Management at Ryerson University for providing me with the knowledge required to perform a project of this magnitude. A special thank you goes to Ravindri Kulatunga, Wendy Duncanson and Amber Duncanson, for providing me with the time I needed to complete this project.

DEDICATION

To my soulmate, Andrea – I'm so proud of everything we've built together, and can't imagine a world without you. Thank you for all the sacrifices you have made for our family. I am so lucky to have met you!

To my son, Damian – Keep having fun in life. Never forget to be happy, and enjoy yourself in everything you do. Your laughter makes everything worth it!

To daughter, Veronica – Please, don't grow up too fast!

To my dog, Scooter – I am thankful to have witnessed your speed, stamina and agility on the trails and in the woods - you are the best dog ever!

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1. ENVIRONMENTAL MONITORING & THE PROTECTION OF HUMAN HEALTH AND THE ENVIRONMENT IN ONTARIO

1.1. THE BENEFITS OF ENVIRONMENTAL MONITORING & THE LEGISLATION USED FOR COMPLIANCE

A fundamental tool used in the protection of human health and the environment, is the collection of empirical data from the land, air and water. The data collected from environmental monitoring has been used by humanity for a variety of beneficial purposes, such as: linking the concentration of an element or compound in soil to the aetiology of a disease (Oliver, 1997), warning people of low air quality conditions (Ontario Ministry of the Environment and Climate Change [MOECC], 2010), preventing the deterioration of an aquatic ecosystems by measuring the temperature of industrial effluent (Environment Canada, 2014), and providing the long term data necessary to identify the origins of an environmental disturbance (Likens & Bailey, 2014). Furthermore, with many sources of **anthropogenic** pollution, from vehicle emissions to the release of contaminants from industrial processes, environmental monitoring is crucial to verify that contaminants exist at concentrations that pose an acceptable level of risk.

In Ontario, Canada, there are two legislative documents that facilitate the protection of humans and the environment against the indiscriminate release of contaminants to the land, air and water. They are the *Environmental Protection Act* of 1990 and the *Ontario Water Resources Act* of 1990. Together, they define if, when and in what concentration, an element or compound can be discharged or emitted, and what permissions are required in order to do so (*Environmental Protection Act*, 1990; *Ontario Water*

Resources Act, 1990). The mechanisms used to grant permission to businesses that discharge or emit pollutants to the environment are known as the Environmental Activity and Sector Registry, and the Environmental Compliance Approval process (MOECC, 2017a). The Environmental Activity and Sector Registry is used for routine business operations related to air and noise pollution that pose a minimal risk, whereas the Environmental Compliance Approval process is used when businesses have unique operations, or operations that pose a large risk to the health of humans and the environment (MOECC, 2017a). Through these mechanisms, the MOECC has a record of potential sources of pollution for inspection and auditing purposes, and is able to stipulate protection measures and operating requirements that must be adhered to by law, for high risk activities (MOECC, 2017b; 2017c). Surprisingly however, while Environmental Compliance Approvals often require a company to set aside money for cleanup (MOECC, 2017d), monitoring the soil at an industrial facility in Ontario is not normally required, unless: (a) there is an upset condition, such as a spill or complaint to the MOECC; or (b) there is a change in land use or the property is sold, as per "O. Reg. 153/04: RECORDS OF SITE CONDITION - PART XV.1 OF THE ACT" (*Environmental Protection Act*, 1990).

In the absence of specific legal requirements, the monitoring of soil is still important as it is created over a lengthy period of time and is considered a non-renewable resource; it provides essential services to humans and the environment, and once soil is contaminated it becomes very difficult to remediate and restore (MOECC, 2011a). Therefore, it is responsible for a business with high risk operations that requires Environmental Compliance Approvals to operate, to monitor the soil proactively. By monitoring the soil for contaminants a business can demonstrate due diligence, and show the public that they are conscious of their environmental impact. A voluntary

monitoring program can provide a company with a competitive advantage, as prospective clients may prefer to do business with a company that is on the Corporate Social Responsibility catalogue, as a promoter of environmental stewardship (Natural Resources Canada, 2016). From a precautionary perspective, the results from monitoring can be compared to regulatory guidelines, and if monitoring is performed regularly, an accumulation in contaminant concentrations can signal the need to improve operational practices. This can be beneficial for worker protection, and to prevent a costly cleanup scenario if there is a change in land use or the property is sold (*Environmental Protection Act*, 1990). Monitoring the soil may also reveal the presence of a contaminant that was not previously considered, and was not submitted to the MOECC as a potential concern, when applying for an Environmental Compliance Approval (MOECC, 2017b).

1.2. THE DERIVATION OF SOIL QUALITY STANDARDS IN ONTARIO

To ascertain if there is a source of anthropogenic contamination in soil, one must first define a background concentration for comparison. For the development of regulatory guidelines in Ontario, the background is defined on provincial wide scale (MOECC, 2011a). Defining a background at this scale originates in the study of exploration geochemistry, and is known as the **geochemical background** (Reimann & Garrett, 2005). It was recommended by Hawkes and Webb (1962), that the geochemical background should be viewed as a range of values, instead of a single absolute value, since the natural abundance of an element in soil varies greatly depending upon location (Matschullat, Ottenstein & Reimann, 2000). The concept of a geochemical background has been used in exploration geochemistry to differentiate between areas that contain minerals of interest and those that do not (Reimann & Garrett, 2005). It can also be used with modifications, in the development of regulatory guidelines, to evaluate whether elevated concentrations of contaminants exist in soil, above a range of background values (MOECC, 1993). The difference, when developing regulatory guidelines for contaminants in soil, is the requirement that background values are derived from data that includes urban areas. Urban areas must be included, so background concentrations are calculated from data that includes ambient, anthropogenic sources of pollution (Reimann & Garrett, 2005). Otherwise, land that has accumulated contaminants from anthropogenic sources, from being populated for decades or centuries, may be classified as contaminated unnecessarily, even if the risk to the health of humans and the environment is acceptable (Alloway et al., 2013).

In Ontario, the document that guides the practical use of background concentrations in soil for environmental monitoring purposes, is called the

Soil, Ground Water and Sediment Standards for Use Under Part XV.1 of the Environmental Protection Act (SSEPA)(MOECC, 2011b). This document provides background concentrations for elements and organic compounds in soil, derived from raw data generated by The Ontario Typical Range (OTR) project (MOECC, 2011b). The OTR project was commissioned by the Province of Ontario, and was conducted in two sampling campaigns, in 1991 for inorganics and 2009 for volatile organic compounds (MOECC, 2016a). Samples were collected in parkland areas, away from point sources of contamination and industry, ensuring that the soil samples collected, were representative of background conditions (MOECC, 1993). The samples were collected at a depth of 0 – 5 cm in all locations, except in areas that were tilled, which were sampled to a maximum depth of 15 cm (MOECC, 1993). Chemical analysis was then performed to determine the leachable concentration of metals, and the data generated was separated into urban and rural land use categories (MOECC, 1993).

The data from the OTR project was then used to create Table 1 of the SSEPA (MOECC, 2011a). Table 1 of the SSEPA is important, as the values it provides are used as regulatory limits. The values were created by the MOECC, and are known as Ontario Typical Range 98 (OTR98) values (MOECC, 1993). The OTR98 values correspond with the 98^{th} percentile of the background data for elements and compounds in specified land use categories (Alloway et al., 2013). This methodology ensures that the majority of sites without point source contamination do not trigger investigations, and those with contamination above the 98^{th} percentile, are investigated further to determine if the contamination is anthropogenic from a point source, or a natural phenomenon (Alloway et al., 2013). For simplicity, OTR98 values calculated for SSEPA Table 1 are separated into two land use categories: the agricultural or other property use category, and the residential, parkland,

institutional, industrial, commercial, and community property use category (MOECC, 2011a).

While the concentrations of elements and compounds found in Table 1 of the SSEPA are used to determine if there is an accumulation of anthropogenic contamination above background values (MOECC, 2011b), the OTR98 values do not represent guideline concentrations for elements and compounds in soil that if exceeded, pose an unacceptable level of risk to the health of humans and the environment (MOECC, 2011a). SSEPA Tables 2 to 8 were generated to perform this function, and are used if an element or compound is found to be above the values in SSEPA Table 1. SSEPA Tables 2 to 8 contain limits for elements and compounds, derived from modelling pathways of exposure for seven generic site conditions, which are representative of the majority of sites in Ontario. For each generic site condition, exposure pathways were modelled for three land use categories: industrial, commercial and community property use; agricultural or other property use; and residential, parkland and institutional property use. This separation exists because it is assumed that the industrial use of land for instance, is not used by toddlers, who are more susceptible to lower concentrations of elements such as Pb (MOECC, 2011a); Canadian Council of the Ministers and Environment [CCME], 2006). The names of the tables in the SSEPA are listed below for reference.

- Table 1: Full Depth Background Site Condition Standards
- Table 2: Full Depth Generic Site Condition Standards in a Potable Ground Water Condition
- Table 3: Full Depth Generic Site Condition Standards in a Non-Potable Ground Water Condition
- Table 4: Stratified Site Condition Standards in a Potable Ground Water Condition

- Table 5: Stratified Site Condition Standards in a Non-Potable Ground Water Condition
- Table 6: Generic Site Condition Standards for Shallow Soils in a Potable Ground Water Condition
- Table 7: Generic Site Condition Standards for Shallow Soils in a Non-Potable Ground Water Condition
- Table 8: Generic Site Condition Standards for Use within 30 m of a Water Body in a Potable Ground Water Condition
- Table 9: Generic Site Condition Standards for Use within 30 m of a Water Body in a Non-Potable Ground Water Condition

SSEPA Tables 2 to 8 were derived using the procedure found in a *Rationale for the Development of Soil and Groundwater Standards for use at Contaminated Sites in Ontario* (RDSWS) (MOECC, 2011a). The RDSWS in turn, relies heavily upon information disseminated by the Canadian Council of the Ministers of the Environment (CCME), in a document known as *A Protocol for the Derivation of Environmental and Human Health Soil Quality Guidelines* (PDEHH) (CCME, 2006). The derivation process is important, as there are allowances in the SSEPA for regulatory limits to be modified based upon site specific conditions. The derivation process also summarizes the various routes of exposure to a contaminant that exists in soil (MOECC, 2011a), which is essential in the creation of a monitoring plan and the interpretation of the data that it generates.

In the RDSWS, four primary items were identified in the development of guideline values for the protection of the human health and the environment: direct contact, ingestion and odour for human health; the factor of a contaminant that leaches into groundwater; the migration of vapour from soil to the inside air; and the protection of terrestrial ecology. Models were

then developed to determine exposure to a contaminant via a multitude of pathways (Figure 1). The amount of a contaminant that an organism, animal or human is exposed to, through an exposure pathway, is called a component (Figure 1) (MOECC, 2011a). And since the fate, transport, **bioavailability**, and **biomagnification** of a contaminant varies depending on the type of soil found at a site, two generic types of soils were modelled: course-textured soils, such as sand and gravel with a median grain size of greater than 75 microns, and fine-textured soils such as silt and clay, with a median grain size of less than 75 microns (MOECC, 2011a).

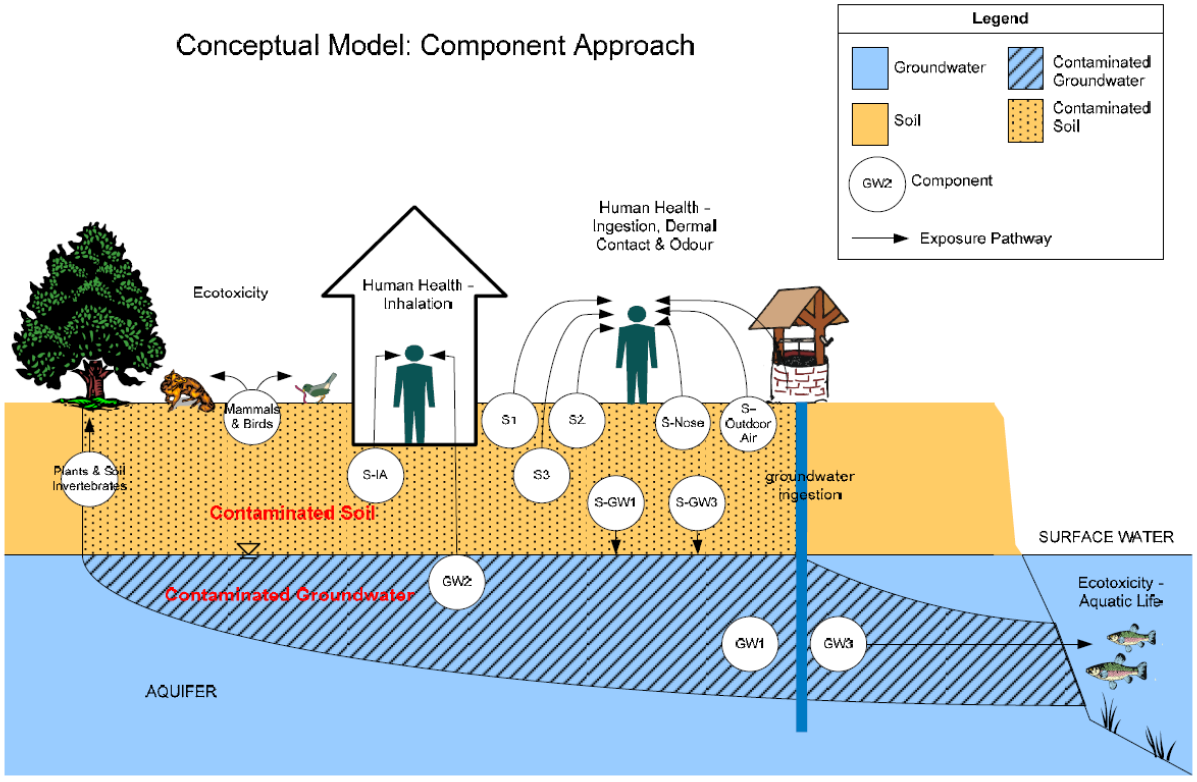

Figure 1: The exposure routes for humans, animals and organisms in the environment. The white circles represent components of a contaminant. Soil components begin with an "S" (MOECC, 2011a).

In industry, the relevant components of Figure 1 are S2, S3, S-Outdoor Air, S-Nose, S-IA, S-GW1, SGW3, Mammals & Birds, Plants & Soil Invertebrates,

and GW2. A description of each component can be found below (MOECC, 2011a), and is associated with the exposure of an adult worker at an industrial site, unless otherwise specified.

- S2 – Represents an exposure to a contaminant from surface soil, through ingestion and inhalation
- S3 – A sub-surface route of exposure to soil, associated with ingestion, dermal exposure and particulate inhalation
- S-Outdoor Air – Represents exposure from the volatilization of a contaminant in soil to air
- S-Nose – Used to determine exposure to unacceptable odours
- S-IA – Models exposure from vapour intrusion into a building from soil
- S-GW1 – Considers the exposure to dependent organisms, animals and humans, from the partitioning of a contaminant into potable groundwater
- S-GW3 – Considers the exposure to dependent organisms, animals and humans, from the partitioning of a contaminant into non-potable groundwater
- Mammals & Birds – Represents the exposure of mammals and avian species
- Plants & Soil Invertebrates – Represents the exposure of plants and soil invertebrates to plants and soil dwelling organisms
- GW2 – Is the exposure from the movement of volatile compounds in the ground water to the air indoors

Once components were identified, a literature review was performed by the MOECC (2011a) to determine: (a) the exposure to a contaminant for a person, animal or organism in each component; and (b) the toxicity from exposure in each component. The toxicological studies reviewed, classify elements and compounds as either a threshold or non-threshold contaminant (CCME, 2006), which determined how it was processed using the RDSWS (MOECC,

2011a). A **threshold contaminant** has a measurable exposure that is required to produce an adverse effect in an organism (Environment Agency, 2009), and requires the use of the threshold model of assessing risk (Calabrese & Baldwin, 2003). In contrast, a **non-threshold contaminant** has no measurable exposure at which it does not produce an adverse effect in an organism (Environment Agency, 2009), and extrapolates the risk of low level exposures using the linear non-threshold model (Calabrese & Baldwin, 2003).

For the protection of environmental health in an industrial setting, the components that were considered when determining the limit for a contaminant in soil were S-GW1, S-GW3, Mammals & Birds, and Plants & Soil Invertebrates (MOECC, 2011a). A concentration in soil was then derived to ensure the protection of the environment by assessing the toxicity of a contaminant through: direct contact; ingestion by plants and invertebrates; and the ingestion of soil and food, for higher trophic level consumers. For the protection of human health, the S2, S3, S-Outdoor Air, S-Nose, S-IA, S-GW1, SGW3 and GW2 components were considered, and compared to the background exposure of an adult to a contaminant. This was determined by assessing all possible sources of exposure such as air, water, food, soil and consumer products, through all possible pathways: inhalation, ingestion and skin absorption (CCME, 2006). Once this was complete, the human health soil quality concentrations for industry were determined by ensuring that the total **tolerable daily intake** of an adult was not exceeded (CCME, 2006). The tolerable daily intake for a threshold contaminant was based upon the daily exposure for a lifetime that produces no observable adverse effects, known as the no-observable-adverse-effect-level. For a non-threshold contaminant, human exposure was set to the lowest levels that were reasonably achievable, taking into account the background concentration of a contaminant, and an acceptable level of risk (CCME, 2006). The risk level used for a non-

threshold contaminant was 10^{-6}, which means that exposure to a contaminant at the specified dose will produce only one instance of cancer in one million people (MOECC, 2011a). Once a concentration for a contaminant in soil, was determined for the protection of human health and the protection of the environment separately, the lowest concentration from the two was selected for use in SSEPA Tables 2 to 8 (MOECC, 2011a).

A summary of elements in terms of their toxicity to humans is provided for reference as a table in Appendix A. The table is a summary of information presented by the Agency for Toxic Substances & Disease Registry (ATSDR), the International Agency for Research on Cancer (IARC), the CCME, and Waters, 1977. The ATSDR is a federal public agency of the U.S. Department of Health and Human Services in the United States of America, and the International Agency for Research on Cancer is the specialized cancer agency of the World Health Organization.

1.3. GUIDING DOCUMENTS TO BE USED IN A SOIL MONITORING PROJECT

To compare contaminant concentrations in soil at an industrial facility, with the limits found in the SSEPA, there are four guiding documents to be used in Canada, published by the Government of Ontario, the CCME and the MOECC. If there is a change in land use or sale of a property the *Guide for completing phase one environmental site assessments under Ontario Regulation 153/04* (GEA1) (MOECC, 2016b), and the *Guide for completing phase two environmental site assessments under Ontario Regulation 153/04*" (GEA2) (MOECC, 2016c) must be adhered to, in addition to the *Protocol for Analytical Methods Used in the Assessment of Properties under Part XV.1 of the Environmental Protection Act* (PAMEPA) (MOECC, 2011c) for laboratory analysis. For the protection of human health and the environment in any scenario, the *Guidance Manual for Environmental Site Characterization in Support of Environmental and Human Health Risk Assessment* (MESC) (CCME, 2016) is another important tool that should be reviewed prior to the development of an environmental monitoring project. When used together, the documents discuss in detail, the process of environmental monitoring at an industrial facility, from site **reconnaissance** to data interpretation. While sample collection in the field is discussed in detail in the MESC, it was noted in the PAMEPA however, that the instructions provided for the sub-sampling of soil in the laboratory were brief. The instructions given were: an inspection of the sample to determine if there are large amounts of free water or petroleum products; the removal of foreign objects such as stones and twigs; and a mixing of the sample prior to the removal of aliquots to form a sub-sample, which should be a minimum of 10 g. The lack of detail in government guides and protocols with regards to sub-sampling, was noted by Dubé et al. (2015), and continues in the three sample preparation methods

suggested for use by the PAMEPA; EPA Method 3050b, EPA Method 3051a, and EPA Method 200.2.

Since the act of sub-sampling is critical, as the uncertainty contribution from the process of sub-sampling, is usually far greater than the uncertainty associated with the analytical technique used in quantitation (Gerlach, Nocerino, Ramsey, Venner, 2003), more detailed instructions may be used to address the following questions:

- Will removing several aliquots from the top of the sample container produce a representative sample if the sample cannot be well mixed?
- What if particle size varies greatly and dense particles immediately fall to the bottom of the container after mixing?
- Will the implement used to remove aliquots from the sample affect the representativeness of the sub-sample?

To provide answers to these questions Pierre Gy's theory of sampling was reviewed, as it describes the types of errors in sampling that lead to an unrepresentative sub-sample, and how they can be minimized. He theorized that a representative sample is taken when all constituents in a lot have an equal probability of being sampled, and if certain constituents in a lot have a zero probability of being sampled, the samples taken for analysis will not be representative of the lot (Gy, 2004). While the theory of sampling was developed primarily for the mining industry, concepts from the theory can be applied to the field of environmental sample analysis, as shown in the work of Nocerino, Schumacher and Dary (2005), Dubé et al. (2015), and Gerlach et al. (2004). Concepts from the theory of sampling with regard to sub-sampling soils in the laboratory are thus reviewed below.

1.3.1. SUB-SAMPLING ERRORS THAT INCREASE VARIABILITY

While the PAMEPA and EPA sample preparation methods do not provide detailed instructions for the creation of a representative sub-sample, the United States Environmental Protection Agency (US EPA) does have a document that was particularly useful in the selection of a sub-sampling technique. The document is called a *Guidance for Obtaining Representative Subsamples from Particulate Laboratory Samples* (GORS), and draws upon Pierre Gy's theory of sampling to provide guidance on sub-sampling techniques that can be used to obtain a representative sub-sample. According to the GORS, there are five types of errors associated with the sub-sampling of particulate materials, which must be minimized to produce a representative sub-sample. The five types of errors are **fundamental error**, **grouping and segregation error**, **increment delimitation error**, **increment extraction error**, and **preparation error** (Gerlach & Nocerino, 2004; Gy, 2004).

The fundamental error is associated with the variability of particles in the sample, and is the minimum sub-sampling error that can be achieved for a sample (Gerlach & Nocerino, 2004). Conceptually, one way to decrease the fundamental error is to increase the mass of the sub-sample. If more particles can be randomly sampled, the sub-sample has a higher probability of being representative of the sample. The second way to reduce the fundamental error is to reduce the maximum particle size. When a sub-sample is removed from a sample with a relatively large maximum particle size, the effect of adding or removing one particle is greater than in a sample with a smaller particle size (Gerlach & Nocerino, 2004); Minnitt, Rice, Spangenberg, 2007). A reduction in particle size for instance, was found to be the dominant

factor in regulating the variability of trace metal concentrations in soil (Dubé et al, 2015).

Grouping and segregation error is caused by an uneven distribution of the target analyte within the sample. If only a few particles within a sample contain an analyte, the analyte may be missed if a grab sample is taken, such as when a small portion of the sample is scooped out of the sample container. A similar situation would arise if the target analyte was bound to dense particles, which in both cases would cause the target analyte concentration to be underreported. To solve this problem, the PAMEPA relies upon mixing, which according to the GORS is not a reliable method to reduce grouping and segregation error (Gerlach & Nocerino, 2004). For example, gravitational effects segregate particles once mixing has finished, and some samples do not mix well to begin with. The GORS recommends that a minimum of 30 increments from a sample are randomly selected and combined to minimize grouping and segregation error (Gerlach & Nocerino, 2004).

The increment delimitation error and the increment extraction error are both associated with the physical extraction of sub-sample increments. The delimitation error involves utilizing an extraction tool that has an equal chance of removing all fractions of the increment to be extracted. If a scoop will be used to extract an increment, the scoop must have squared off sides and a squared off bottom to minimize the delimitation error (Gerlach & Nocerino, 2004; Nocerino et al., 2005). If a round scoop is used, there will be more sample taken from the top of the sample than the bottom, and if a target analyte is bound to particles with a relatively low density, it will be preferentially sampled. The increment extraction error refers to the error associated with the inclusion or exclusion of particles at the boundary of the sampling device. If the centre of gravity of a particle is within the selected increment, it should be included in the increment. This may not

always occur if the edge of the sampling device has not been designed properly (Gerlach & Nocerino, 2004). The device used for increment extraction should also have an inside diameter that is at minimum, three times greater than the largest particle in the sample (Nocerino et al., 2005).

The preparation error is associated with errors arising between the time the sample is collected and the time at which the sub-sample is composed for analysis. Preparation error includes sample losses, contamination and alteration, as well as the uncertainty associated sample handling, shipping, storage and preservation, and anything that alters the concentration of the analyte from the time of sampling to the time of analysis (Gerlach & Nocerino, 2004).

1.3.2. FOUR SUB-SAMPLING TECHNIQUES FOR THE REDUCTION OF SUB-SAMPLING ERRORS

The four highest ranked techniques in the GORS are: sectorial splitting, paper cone sectorial splitting, rifle splitting and incremental sampling (Gerlach & Nocerino, 2004). A description of each is included below.

Sectorial spitting (Figure 2) is ranked first, and involves using a rotating machine with ridges and valleys to create several sub-samples. The sample is poured into a vibrating receiving vessel at the top of the machine that slowly allows particles to fall into the rotating cone via a funnel. Containers are connected to the bottom of each valley of the rotating cone to capture the sample particles as they fall (Pitard, 1993). Sectorial splitters have a low grouping and segregation error due to the vibrating

receiving vessel allowing particles of different sizes to emerge independently of each other (Gerlach & Nocerino, 2004) at a slow rate (Dubé et al, 2015). The delimitation error and increment extraction error are also low due to the machine processing the entire sample (Pitard, 1993).

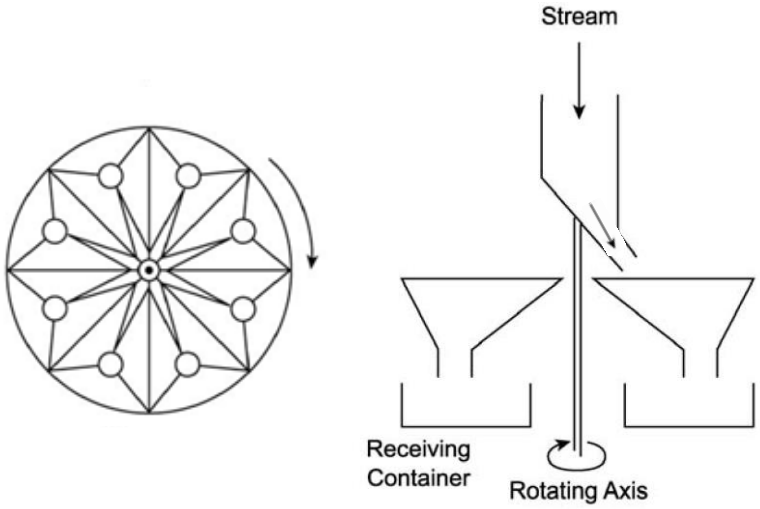

Figure 2: Sectorial Splitter (adopted from Gerlach & Nocerino, 2004)

Instead of utilizing a machine, paper cone sectorial splitting (Figure 3), which is ranked second in the GORS, allows an analyst to approximate a sectorial splitter using beakers, a funnel and a piece of paper. The piece of paper is folded to produce ridges and valleys with a receiving beaker placed at the bottom of each valley. The sample is poured from the beaker into a funnel as the funnel is rotated around the paper, delivering increments of sample to each receiving beaker. The advantage to this method of sub-sampling is that the apparatus is easily cleaned and the paper is disposable. While the method mimics the benefits of a sectorial splitter, the analyst must be extremely careful not to spill the sample and disrupt the apparatus while rotating the funnel (Gerlach & Nocerino, 2004).

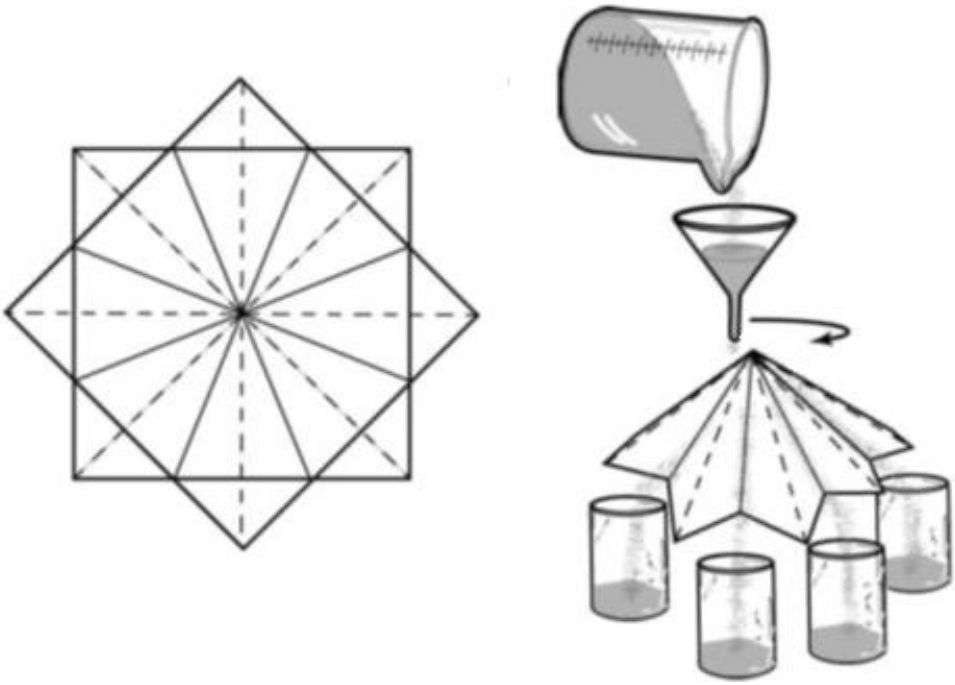

Figure 3: Paper Cone Sectorial Splitter (adopted from Gerlach & Nocerino, 2004)

The technique ranked third, is incremental splitting. In this method, the sample is poured evenly onto a surface and increments are removed using a sampling device. The sampling device should be designed to minimize increment delimitation error and increment extraction error, and to minimize the grouping and segregation error; the number of increments to be taken from the sample should be at least 30. The increments should also be taken at random and be roughly the same mass (Gerlach & Nocerino, 2004). A disadvantage to the incremental sampling method arises when the number of increments is below 30, and if there are only a few particles with a high concentration of analyte (Gerlach & Nocerino, 2004). If used correctly however, with the proper sub-sampling implements, incremental splitting

facilitates an analyst to achieve the data quality requirements of an environmental monitoring project (Gerlach & Nocerino, 2004).

Rifle splitting (Figure 4) is ranked fourth and utilizes a piece of apparatus that divides a sample into two portions. The analyst pours the sample back and forth across the top of the apparatus, which is divided into an even number of chutes. Each chute is directed to one of two bins that collect the sample. The odd numbered chutes are all directed to the same bin, and the even numbered chutes are directed to the other bin. Each bin is thus composed of several increments of sample. The process is then repeated until the required amount of sub-sample is obtained (Crosby & Patel, 1995). Rifle splitters need as much as six passes to minimize the uncertainty associated with this method (Gerlach & Nocerino, 2004).

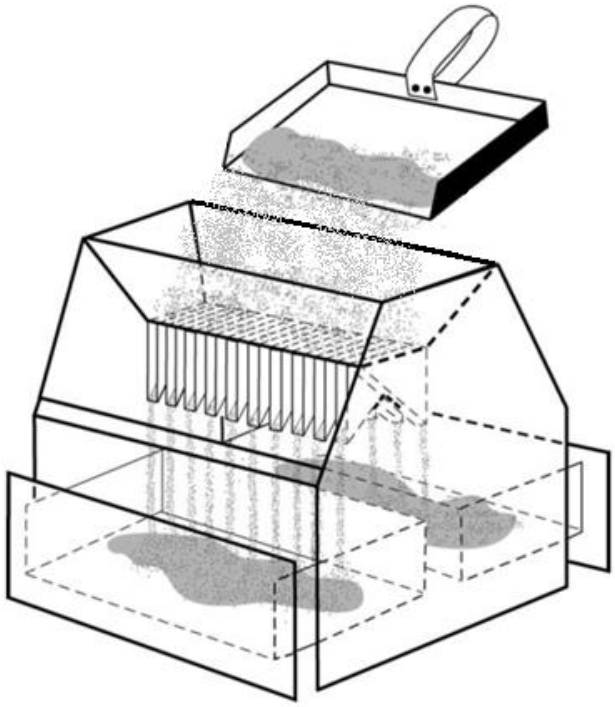

Figure 4: Rifle Splitter (adopted from Gerlach & Nocerino, 2004)

1.4. RESEARCH OBJECTIVES

Since soil is considered a non-renewable resource, which provides essential services for humanity and the environment, thus the contamination of soil can be problematic (MOECC, 2011a). While laws and regulations are in place to monitor soils after upset conditions, and when a land use changes or a property is sold (*Environmental Protection Act*, 1990), it may be prudent for a company to analyze the soil on their property proactively. Well-developed guides are available for soil monitoring projects, regulatory guidelines have been established to ensure compliance, and a site specific background can be calculated to determine if operations at a facility are causing an accumulation of contaminants in soil. As a result of these factors, a project was developed at an industrial facility, with following research objectives:

1. to compare contaminant concentrations in the soil with background values in SSEPA Table 1;
2. to determine whether contaminant concentrations pose an unacceptable level of risk to the health of humans and the environment, if contaminant concentrations are above the values in SSEPA Table 1;
3. to determine whether operations have caused an accumulation of contaminants in the soil; and
4. to establish a background for future monitoring purposes.

Following a short note on confidentiality, the remainder of this paper is organized in the sequence it was executed. The methods chapter will describe the industrial facility, the sampling plan, sample collection, laboratory preparation and analysis, and the statistical methods used for data interpretation. Following the Methods chapter, the results will be presented in the Results & Discussion chapter, following by conclusions and

future work to be performed at the facility, in the Conclusions and Recommendations Chapter.

In order to perform this project in conjunction with Environmental Applied Science and Management program at Ryerson University, the company that operates the industrial facility, imposed a requirement that their name and address could not be used in this paper. This includes versions of the project paper found online and in print.

2. METHODS

In the practical phase of this project, the tasks of site reconnaissance, sample collection, sample preparation, chemical analysis and data interpretation were critical. Therefore, the GEA1, GEA2 and MESC were used to develop criteria to guide this project, which are listed below:

i) knowledge of site history, environmental monitoring practices, and potential sources of contamination, based upon a review of company documents and interviews with employees;

ii) the creation of a sampling plan using the information gathered during site reconnaissance, time and budget considerations and quality control procedures;

iii) the collection of samples using acceptable techniques, clean up practices, and adherence to the sampling plan to avoid bias;

iv) the preparation and chemical analysis of samples using accredited methods and quality control;

v) an estimation of uncertainty at the 95% confidence level; and

vi) an interpretation of the data using regulatory guidelines, site reconnaissance, and statistical methods.

The methods section is organized to ensure that each criterion is achieved, and begins with an introduction to the industrial facility located in Toronto, Ontario, Canada, where soil samples were collected analyzed.

2.1. SITE RECONAISSENCE

The company focuses upon providing a variety of science and engineering services to the energy sector. There are several buildings operated by the company inside the complex, including one that was designated to serve and function as an analytical chemistry laboratory. Since the laboratory, as it will be called in this paper, was built in 1991, it has provided the infrastructure necessary to facilitate the execution of waste processing and analysis projects from internal and external clients, as well as to support large environmental assessment, decommissioning, and maintenance projects for the nuclear industry. As a result of these activities, Environmental Compliance Approvals have been obtained, for the company to discharge industrial pollutants to the air through fume hoods, and to transfer and process industrial waste (MOECC, 2016d). The company also maintains a radioactive license issued by the Canadian Nuclear Safety Commission. The license requires the use of high efficiency particulate arrestance filters in the air exhaust ducts of fume hoods and an analysis of the combined air exhaust system, for the beta emitting isotope of hydrogen, known as tritium. These protection measures are present in the radioactive area of the laboratory, and are necessary to prevent radioactive particulate and excessive amounts of tritium from escaping the laboratory.

In terms of water quality protection, waste water drains in the laboratory are routed to a series of holding tanks, where waste water is retained for analysis, prior to discharge into the sewer system. The tank water is analyzed to ensure that tritium and gamma emitting isotopes are below unconditional clearance limits, and that the parameters listed in Table 1 of the "Toronto Municipal Code Chapter 681, Sewers" (City of Toronto, 2016) (Appendix B) are also below the specified limits. An analysis of groundwater was also performed in early 2016, where water from sump pits was analyzed to

determine the concentration of contaminants in groundwater. Zn was the only element found above background values in groundwater.

While monitoring systems were present for stack emissions, waste water discharge, and groundwater, there had been no analysis of non-radiological parameters in the soil surrounding the laboratory, prior to the execution of this project. This was primarily due to the absence of a legal requirement to do so, as per Ontario Regulation 153/04 (*Environmental Protection Act*, 1990). However, despite the absence of a legal monitoring requirement, activities at the laboratory exist that may have contributed elements and compounds to the soil. These include, but are not limited to the transfer, storage and disposal of lead bricks used for radiation shielding, the daily transfer of lab waste to large garbage containers, the delivery and relocation of waste containing drums around the facility, renovations to the roof and exhaust system, and the storage of old pallets in the past that were pressure treated with chromated copper arsenate.

In 2016, there were two events that further demonstrated a need to analyze the soil in the area surrounding of the laboratory. Firstly, between the months of September and December, there was a major laboratory renovation that included a campaign to dispose of legacy waste. The waste included old instrumentation and samples, lab supplies, building materials and waste chemicals. The waste was stored in various places in the building, and the waste collection areas outside the building. The waste included several potentially toxic elements and compounds:

- 3 kg of elemental Hg, partially dissolved in a mixture of hydrochloric and nitric acid;
- shavings, cuttings and filings from machining metallic components for forensic testing;
- household and industrial sized batteries containing Ni, Cd and Pb;

- natural U pellets;
- several 10 and 20 L pails containing metallic waste, precipitated as hydroxides from sample analysis; and
- 5000 kg of solid lead bricks.

In addition to the items above, the renovation included moving 30 to 40, 55 gallon drums of mixed liquid waste to another building, as well as the equipment and machinery used to process the waste. The drums contained concentrated mixtures of toxic metals and metalloids, polychlorinated biphenyls, acids, and other compounds. At times the drums were temporarily stored in the Hazardous Waste Transfer Location (Figure 5) on the soil at the east side of building.

Secondly, in the latter part of September 2016, there was an accidental spill that occurred, where several industrial sized, lead-acid batteries tipped over on the bed of large delivery truck. Sulfuric acid leaked out of the truck onto the asphalt, concrete curb and soil near the sample receiving area of the laboratory. The MOECC was notified of the spill and did not require further action after clean up, since the spill was stopped before reaching the storm water drain. The spill did, however, highlight a need for the company to analyze soil at the laboratory to use as a baseline for legal purposes, if another company caused a spill.

Based upon interviews of employees at the company, it was noted that in the absence of empirical data, there was a fear that soil in specific areas at the laboratory may have elevated concentrations of elements and compounds above regulatory limits. Even though employees generally believed that the risk of contamination from daily operations was low, there were concerns associated with the events previously discussed. There were thus four locations of interest (Figure 5) which were thought to have the highest

probability of contaminant loading, and are referred to in this paper according to the following list.

1. Waste Collection Area #1 – The majority of laboratory waste from daily operations is stored in this location. Prior to 2015, the waste bins were open to the environment. Historically, pallets that contained chromated copper arsenates were stacked in this location, as well as drums of chemicals and larger equipment.
2. Lead-acid Spill Location – The area affected by the accidental lead-acid battery spill.
3. Waste Collection Area #2 – The waste disposal area for metals, large items, and laboratory waste from the east side of the building. Prior to 2015, the waste bins were open to the environment.
4. Hazardous Waste Transfer Location – Hazardous waste is stored in a room at the east side of the building. The waste is transferred to larger waste containers by the waste transfer company, in and around this area. This area was also used as temporary storage for large, bulky items and drums of waste during the laboratory renovation and legacy waste disposal campaign.

Figure 5: Aerial perspective of the analytical chemistry laboratory, with the four locations of interest outlined in red (Google Maps, 2018).

2.2 SAMPLING PLAN CREATION AND QUALITY CONTROL

In the development of a sampling plan, the MESC states that 'time, money and human resources' (CCME, 2016) are important factors when deciding on scope. As a result, the project was focused upon providing results for elements and compounds that were of interest after site reconnaissance, while taking instrument availability and sampling requirements into consideration. Since 5000 kg of Pb and 3 kg of Hg were removed during the legacy waste disposal initiative, there was a battery acid spill containing Pb, and groundwater sampling had revealed an elevated concentration of Zn, it was decided to design the sampling plan for these metals. The instruments available for use in this project were an Inductively Coupled Mass Spectrometer (ICP-MS) and an Inductively Coupled Atomic Emission Spectrometer (ICP-AES), so the list of analytes was increased to include metals and metalloids that could be analyzed in conjunction with Hg, Pb and Zn. The full list of elements to be analyzed is as follows: Ag, As, Ba, Be, Cd, Co, Cr, Cu, Hg, Mo, Ni, Pb, Sb, Se, , Tl, U, V and Zn. They are listed as elements of concern in the "*Canadian Soil Quality Guidelines for the Protection of Environmental and Human Health*" (CCME, 2006) and, in the case of Hg, has low regulatory limits (Table 1). Since the project was exploratory, and the majority of direct exposure pathways for humans at an industrial site are determined by the top 1.5 meters of soil (CCME, 2016), sampling was performed at the surface horizon. B was not analyzed as its preparation method in surface soils (MOECC, 2011c) differs from the acid leaching method (page 35) required for other elements. B is also not a large component of the waste produced at the facility.

After focusing the scope, several quality control components from the MESC and GEA2 were incorporated in the project. They are included in the

list below, with a brief description. Quality control for laboratory preparation and analysis will be presented on pages 38 and 39.

- Field Replicates – Field replicates should be collected every 20 samples (MOECC, 2016c). They are used to assess the sampling design, and whether the frequency and resolution in the sampling plan is appropriate (CCME, 2016). Two field replicates were collected at sampling points 5R and 7R (Figure 8).
- Trip Blank (TB) – A TB should be prepared and analyzed for every 20 samples collected. The TB is used to assess whether contamination occurred during sample transportation and storage (CCME, 2016). Two TBs containing deionized water were prepared prior to sample collection.
- Field Blank (FB) - A FB should be prepared and analyzed for every 20 samples collected. The FB is used to assess whether contamination occurred during sample collection (CCME, 2016). Two FBs containing deionized water were prepared prior to sample collection, and were opened during the collection of sample 1 and sample 21 (Figure 8).
- Equipment Blank (EB) – An EB is used to assess the contribution of analytes from the sampling apparatus and cross contamination between samples (CCME, 2016). The equipment used to collect the samples was cleaned according to the sample collection procedure found on page 33, and then rinsed with deionized water into a high density polyethylene bottle (Thermofisher).

Once the areas of interest were identified, the scope of the project was determined, and the quality control requirements were established, the sampling plan was designed using two approaches; cluster sampling and systematic grid sampling. Cluster sampling is recommended at the initial

phase of a site assessment, when specific areas are thought to be at the highest risk of contamination (CCME, 2016; US EPA, 2002). It is a focused method of sampling where sampling points are chosen within close proximity, in areas such as the ones in this project (US EPA, 2002). Based upon the size and shape of the areas of interest, 5 samples were taken in each cluster area, increasing the sample density and resolution of the sampling plan. For Waste Collection Area #1 and the Lead-acid Spill Location #2, the shape of the clusters are shown in Figure 6, while the cluster design for Waste Collection Area #2 and the Hazardous Waste Transfer Location, are shown in Figure 7. 5 sampling points were selected from each of the 4 critical locations (Figure 5), providing a total of 20 samples to be collected through cluster sampling.

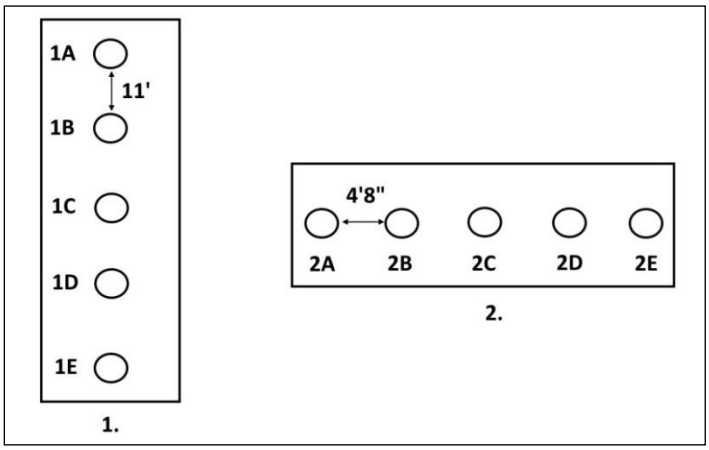

Figure 6: Cluster sample spacing of areas #1 and #2 of Figure 5

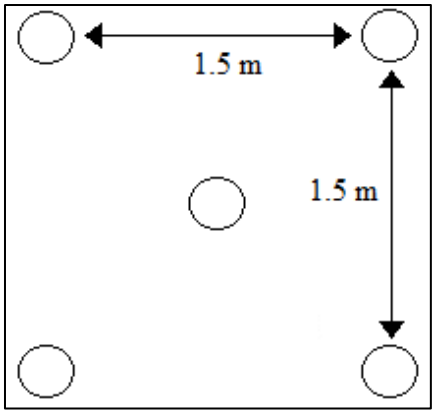

Figure 7: Cluster sample spacing of areas #3 and #4 of Figure 5

After the clusters for the areas of interest were mapped (Figure 5), systemic grid sampling was used to determine general sampling locations (Figure 5), which were thought to be at the lowest risk of contamination, and if the cluster sampled showed contamination, could provide the data required to calculate a site specific background. Another 10 sampling locations were then chosen using the systemic grid sampling method, with samples taken every other quadrant. Field replicates were collected at location 5 and 7, as close to the original sampling location as possible, and are named 5R and 7R. This provided an additional 22 sampling points, for a total of 32 sampling points for sample collection (Figure 5).

To remove bias, the sampling locations were selected in order to be measured easily with a tape measure, using reference points such as the corner of the building. If the corner of the building was not available, other reference points such as the fence guarding the air conditioning units were used. This was the case for sampling location 8, which was taken at a distance of 2.2 m from the fence. Where possible all of the grid samples were taken at a distance of 3.0 m from the building, except in specific cases where this was not feasible such as location 11 and 12 (Figure 8), where the

sampling point was 6.1 m from the building. Therefore, there was an easy to use sampling plan and judgement was eliminated during sample collection.

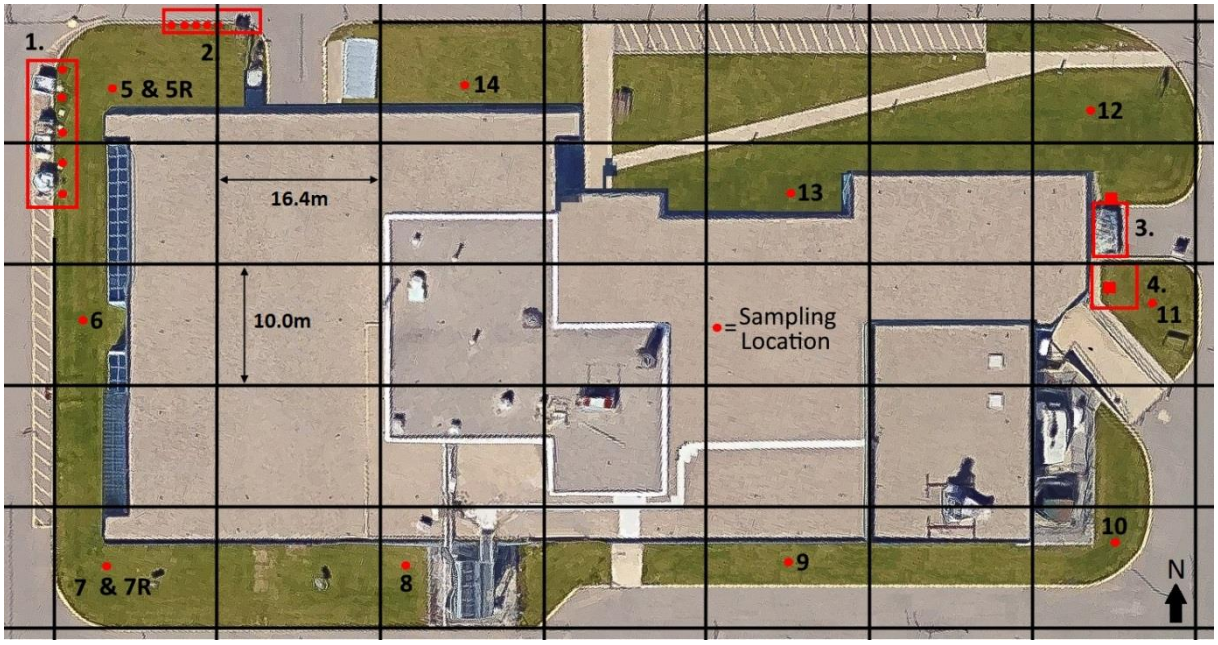

Figure 8: Sampling locations identified at the Analytical Chemistry Laboratory. The red dots represent the points at which the samples were collected. The areas of interest are highlighted in red. For areas #1 and #2, samples were collected using the spacing in Figure 4. For areas #3 and #4, samples were collected using the spacing in Figure 5, and the cluster is represented by the red square (Google Maps, 2018).

2.3. SAMPLE COLLECTION

The samples were collected with the use of a Shelby tube. A Shelby tube was used because the soil was soft and the tube could be easily pushed into the soil to collect the sample. Shelby tubes are recommended by the MESC for use in geotechnical investigations and sample collection for chemical analysis (CCME, 2016). A Shelby tube takes a core sample that is relatively undisturbed, and can also be manufactured in a variety of sizes (CCME, 1993; 2006). The Shelby tube selected for use in this project was 10.2 cm in diameter and 25.4 cm in length because the depth of soil sampling was limited by the company to 30.5 cm, SSEPA limits are based upon soil samples taken at a maximum depth of 15 cm, and the majority of exposure pathways for humans, animals and other organisms applies to soil that is located at or near the surface (CCME, 2016). A mark was thus placed 13 cm from the bottom of the Shelby tube, which enabled a 500 mL column of soil to be removed by the Shelby tube. With the help of a high density polyethylene scoop, the sample was transferred with the aid of a funnel to a new 500 mL, wide mouthed, high density polyethylene jar (Thermofisher). The jars were certified to be contaminant free according to the US EPA guidelines (Thermofisher, 2016). In between the collection of each sample, the Shelby tube was scraped clean with a metal scoop, wiped with fresh paper towel, and immersed in a bucket containing a mixture of deionized water and Fisherbrand™ Sparkleen™ 1 detergent, where it was scrubbed with a nylon brush. The Shelby tube was then transferred into a second bucket filled with deionized water, after which it was removed and wiped dry with a towel. The high density polyethylene and metal scoops were also cleaned using the same technique, and after sample collection, the samples were stored in a fridge set to a temperature of 4°C.

2.4. LABORATORY PREPARATION, ANALYSIS AND QUALITY CONTROL

The fundamental error of sampling was minimized as much as possible by maximizing the mass of the sub-sample, and reducing particle size by crushing and grinding the sub-sample before an aliquot was taken for analysis. With the tools available, incremental splitting was chosen as the method of sub-sampling, with the number of increments set to 30 to reduce grouping and segregation error. To minimize increment and delimitation error, a flat bottomed polytetrafluoroethylene scoop was used. Increment extraction error was minimized as the scoop was greater than three times the size of the largest particle. To determine the variability associated with the incremental sampling method, sample 6 was sub-sampled a total of 10 times with 30 increments taken for each sub-sample. The entire sample was thus converted into 10 sub-samples, which were processed and analyzed separately. This was done to evaluate the uncertainty associated with the entire laboratory process including sub-sampling, as compared to the uncertainty that is normally reported by a laboratory, which is associated with the digestion and analytical method used for analysis.

2.4.1. THE SUB-SAMPLING AND DIGESTION PROCEDURE

After sample collection, the jars were opened and inspected as per PAMEPA requirements. Debris such as roots and rocks were removed, and large chunks were broken up with a polypropylene rod. The rod was also used to mix the samples, and to facilitate pouring at steady rate. Each sample was poured to create 5 separate lines on two plastic trays. Once the entire sample was poured out of the beaker, 30 increments were randomly taken from the sample with a metal scoop, and transferred to a tared glass beaker. The weight of each increment was between 1.70 and 2.30 g. In between each sample

the plastic tray, the metal scoop and polypropylene rod were washed with Fisherbrand™ Sparkleen™ 1 detergent, rinsed with deionized water, and wiped dry with paper towel. After the sub-samples were formed, the sample beakers were placed inside an oven to dry for 48 hours at a temperature of 55°C (MOECC, 2011c). This temperature ensured that volatile metallic compounds such as those containing Hg were not lost (US EPA, 1994).

After drying the sub-samples they were ground using a mortar and pestle to reduce particle size, and passed through a 355 micrometre sieve (MOECC, 2011c). After sieving, the samples were transferred to a new high density polyethylene bottle (Nalgene). In between each sample the mortar and pestle was scrubbed clean using Fisherbrand™ Sparkleen™ 1 detergent, rinsed with deionized water and wiped dry with a paper towel. The sieve was also scrubbed and dried in the same manner. Once all of the samples, replicates, and blanks had been prepared, they were ready for microwave digestion.

The determination of leachable metals was the primary concern of this project, as the acid leaching of soils is the method used most frequently, to approximate the **mobility** and bioavailability of metals in samples of soil (Link, Walter, & Kingston, 1998). The mobility and bioavailability of metals may also be evaluated through **Tessier Fractionation** (Tessier, Bisson & Campbell , 1979), however in this project the results were compared with regulatory guidelines that are based upon an acid leaching process. Thus, based upon recommendations in the PAMEPA, the samples were digested using US EPA method 3051a as a guide. This method improves performance when compared to US EPA Method 3050b, for Ag and Sb, through the addition of hydrochloric acid (US EPA, 2007; Chena & Ma, 1998; Link et al., 1998). The use of closed microwave digestion vessels is also specified, which prevents the loss of volatile species such as mercury and organo-arsenic compounds (Carter & Jirka, 1987). The microwave (CEM) contained 12 high pressure

polytetrafluoroethylene vessels, that are continuously monitored with two infrared sensors and a temperature probe located in one of the vessels. The temperature feedback and control provided by the microwave, aids in the reproducibility of leachate procedures (Link et al., 1998). This was a critical component of the project, as the analytical results were compared to guideline values in Table 1 of the SSEPA, which were generated using specific leachate procedures.

In preparation for digestion, the microwave digestion vessels were cleaned using a 1:1 solution of deionized water and concentrated hydrocholoric acid (Fisherbrand™) for 2 hours at 95°C, followed by a 1:1 solution of deionized water and concentrated nitric acid (Fisherbrand™) for another 2 hours at 95°C (EPA, 2007). After cooling the acids were poured into a waste container, and the vessels were rinsed with deionized water, shaken and dried with a stream of nitrogen gas. An aliquot of sample was then transferred to a digestion vessel using a polyethylene scoop. The aliquot was weighed on a four decimal point balance with a target of 0.20g. To each vessel 9mL of concentrated nitric acid (Fisherbrand™) and 3mL of concentrated hydrochloric acid (Fisherbrand™) was added. The vessel was closed immediately after the addition of acid and weighed on the same balance. Once all 12 digestion vessels were prepared and placed in the microwave carousel, the carousel was placed inside the microwave. The microwave was programmed to raise the temperature to 175 °C in the first 5.5 minutes, and to hold the temperature inside each vessel constant for another 4.5 minutes (EPA, 2007).

Once the digestion program was finished the vessels were allowed to cool for 1.5 hours. Each vessel was inspected to determine if venting occurred during the digestion procedure, and was weighed on a four decimal balance. If the loss of weight in a microwave vessel exceeded 1% for the sum

of the reagents and sample, it was deemed to be compromised and another aliquot was digested (EPA, 2007). The microwave vessels were opened inside a fume hood and the contents were transferred to new, 50 mL polypropylene containers, using deionized water with a resistivity of 18 MΩ·cm. Any remaining solids were allowed to settle overnight prior to analysis by inductively coupled plasma atomic emission spectroscopy and inductively coupled plasma mass spectrometry. While cleaning is only required when moving from high concentration samples to low concentrations samples (EPA, 2007), the digestion vessels were cleaned between each run to enhance the integrity of the analysis. A modified cleaning procedure between each run was used, with 9 mL of concentrated nitric acid (Fisherbrand™) and 2 mL of concentrated hydrochloric acid (Fisherbrand™) added to each vessel. The vessels where then heated to a temperature of 120°C for 20 minutes and allowed to cool for 30 minutes. The cleaning solution was discarded, and the vessels were rinsed with deionized water before being dried with a stream of nitrogen gas.

2.4.2. CHEMICAL ANALYSIS AND QUALITY CONTROL

Once the samples, replicates and quality control samples were digested, the solutions were submitted to the company's ICP-AES and ICP-MS technicians for analysis. To avoid bias, the solutions were given to the operators, without providing them with project specific information. The laboratory and relevant ICP-AES and ICP-MS methods are accredited to the ISO 17025 standard by the Standards Council of Canada, and the analysis was performed with quality control procedures specified in the PAMEPA and relevant EPA methods. This includes the use of method blanks, sample spikes, replicates and laboratory control samples (LCS) (EPA, 2007; MOECC, 2011c). Since a total of

32 samples were collected, at least two quality control samples of each type were prepared and analyzed. A description of the quality control samples is found below.

- Method Preparation Blank (MB) – A MB should be a matrix matched sample that is processed through the entire laboratory procedure. It should be free of the target analyte(s), analyzed every 20 samples, and the results should be less than the reporting limits (MOECC, 2011c). In this project, since blank soil samples do not exist, a sample of Ottawa Sand was used as the MB.
- Laboratory Control Sample – A laboratory prepared spike that should be analyzed every 20 samples (MOECC, 2011c). The recovery should be between 80 % and 120 %. A solution containing the elements of interest (Inorganic Ventures) was thus added to a digestion vessel containing SiO_2, prior to microwave digestion.
- Matrix Spike (MXS) or Certified Reference Material (CRM) – According to the PAMEPA (MOECC, 2011c), either a MXS or CRM must be analyzed every 20 samples, and is used to assess laboratory accuracy with matrix effects. In this project, one MXS was analyzed, along with three CRM sub-samples. For the MXS, a solution containing specific concentrations of the elements of interest, was added to the first sample after digestion, prior to analysis. For the CRM, NIST 2711 was used, which contained all of the elements of interest except Mo. NIST 2711 has been used in the evaluation of EPA Method 3051a by Chen & Ma (1998). The recovery for both the MXS and CRM should be between 70% and 130%.
- Sample Duplicate (SMPD) – A sample duplicate must be analyzed every 20 samples and the replicate difference (RPD) should be less than 30 % in soils, except if the result is less than 5 times greater than the

method detection limit (MOECC, 2011c). The sample chosen for the SMPD was sample 2.

The data generated from the quality control samples, in addition to results from the soil samples themselves, are presented in the Results & Discussion chapter of this paper.

2.5. THE METHOD USED TO EXPRESS UNCERTAINTY

Uncertainty for the CRM and LCS was calculated at the 95% confidence level during method validation at the laboratory, prior to the beginning of this project. According to the laboratory, sources of uncertainty were evaluated and only those that were greater than one-third of the highest source of uncertainty were included in the combined standard uncertainty, according to instructions in the "Evaluation of measurement data – Guide to the Expression of Uncertainty in Measurement" (Bureau Interntaionl des Poids et Mesures, 2008). This included: the standard uncertainty associated with the reference value of each analyte in the CRM; the standard uncertainty of CRM measurements made within the last two years; and the standard uncertainty associated with systemic bias correction. Standard uncertainty was combined using the root sum of squares method (Bureau Interntaionl des Poids et Mesures, 2008), and was multiplied by a factor of 2.32 to provide an expanded uncertainty at the 95% confidence level. The method validation procedure used for ICP-AES and ICP-MS was audited by the Standards Council of Canada.

The uncertainty reported for sample, SMPD and MXS results, differs from the uncertainty determined by the laboratory in their analysis of CRM and LCS samples. The uncertainty reported for sample, SMPD and MXS results includes the uncertainty component of the sub-sampling process, analyzed by repeating the sub-sampling process 10 times, on sample 6. This measure of precision

was used to replace the repeatability portion of the combined standard uncertainty calculated by the laboratory, as it did not previously contain the variability arising from sub-sampling. Prior to calculating the standard deviation for the 10 measurements, a two tailed **Grubbs' Test** was performed to exclude outliers at the 95% confidence level. Once outliers were excluded and the standard deviation was calculated for an element, uncertainty components were combined using the root sum of squares method (Bureau International des Poids et Mesures, 2008). The combined standard uncertainty was then multiplied by the required factor, depending on the degrees of freedom for each element after the removal of outliers, to provide an expanded uncertainty at the 95% confidence level (Bureau International des Poids et Mesures, 2008).

2.6. THE METHODS USED FOR DATA INTERPRETATION

To interpret the data, it was important to select the appropriate tables from the SSEPA for comparison. To determine whether element concentrations were above background values, SSEPA Table 1 was selected (Table 1), as it provides background values for regulatory purposes in Ontario. SSEPA Table 3 was also used to determine whether human health and the environment were being protected. SSEPA Table 3 was appropriate, because during site reconnaissance it was noted that there are no wells or water bodies near the laboratory, which is consistent with a non-potable ground water condition, not within 30 metres of a water body (page 6). The guideline values from SSEPA Tables 1 and 3 are can be found in Table 1 below.

Element	SSEPA Table 1 *Background Values* (mg/kg)	SSEPA Table 3 *Protection of Human Health & Environment* (mg/kg)
Ag	0.5	40
As	18	18
Ba	220	670
Be	2.5	8
Cd	1.2	1.9
Co	21	80
Cr	70	160
Cu	92	230
Hg	0.27	3.9
Mo	2	40
Ni	82	270
Pb	120	120
Sb	1.3	40
Se	1.5	5.5
Tl	1	3.3
U	2.5	33
V	86	86
Zn	290	340

Table 1 – SSEPA guideline limits for the industrial land use category. SSEPA Table 1 contains background values, and SSEPA Table 3 contains values used to protect human health and the environment (MOECC, 2011b).

Prior to the comparison of project results to SSEPA values, outliers were removed from the data set using Grubbs' test. Data points were removed if they were outside the 95% confidence level of the normally distributed data for an element. The remaining results were then averaged for comparison with the SSEPA. The outliers removed were not simply discarded, and will be discussed in the Results & Discussion chapter of this paper. A statistical analysis was also performed to determine if any of the locations of interest (Figure 5) had statistically significant elevated concentrations for an element. The data was separated into five groups for each element, signifying the four areas of interest and a fifth group containing the background samples with the least probability of being contaminated (Figure 8). The statistical tool used for this determination, was a single variable analysis of variance (**ANOVA**).

An ANOVA compares the variability between groups of data to the variability of the data within each group. In the ANOVA an F-value, which is defined as the variance between groups divided by the variance within the groups, is compared to values in an F-table, which are derived based upon the number of groups, the number of data points within a group, and a significance level or alpha, normally set to 0.05. If the F-value is larger than the appropriate F-value in the F-table, known as the F-critical value, there is at least one group that is statistically different than the other groups in the ANOVA (Minitab, 2017).

Two ANOVA tests were performed to determine whether; (a) there was one or more groupings for an element that contained a statistically different distribution of results than the other groups; and (b) if the distribution of results from the group containing the highest mean concentration for an element, was statistically different from the distribution of results from the other groups. Through this analysis, groupings with the highest mean

concentration for an element, that can be viewed as being from a statistically different population were identified, which was used to determine the locations of interest that contained elevated concentrations of contaminants. A flow chart showing the logic used for this determination is presented in Figure 9. This procedure is similar to the one used by Dubé et al. (2015), where ANOVA was used to determine variances in metal concentrations at various sampling stages in their experiment. If the logic determined that a grouping may contain a statistically higher mean concentration of an element, the results for an element were investigated further, to determine if there was a practical significance to the results.

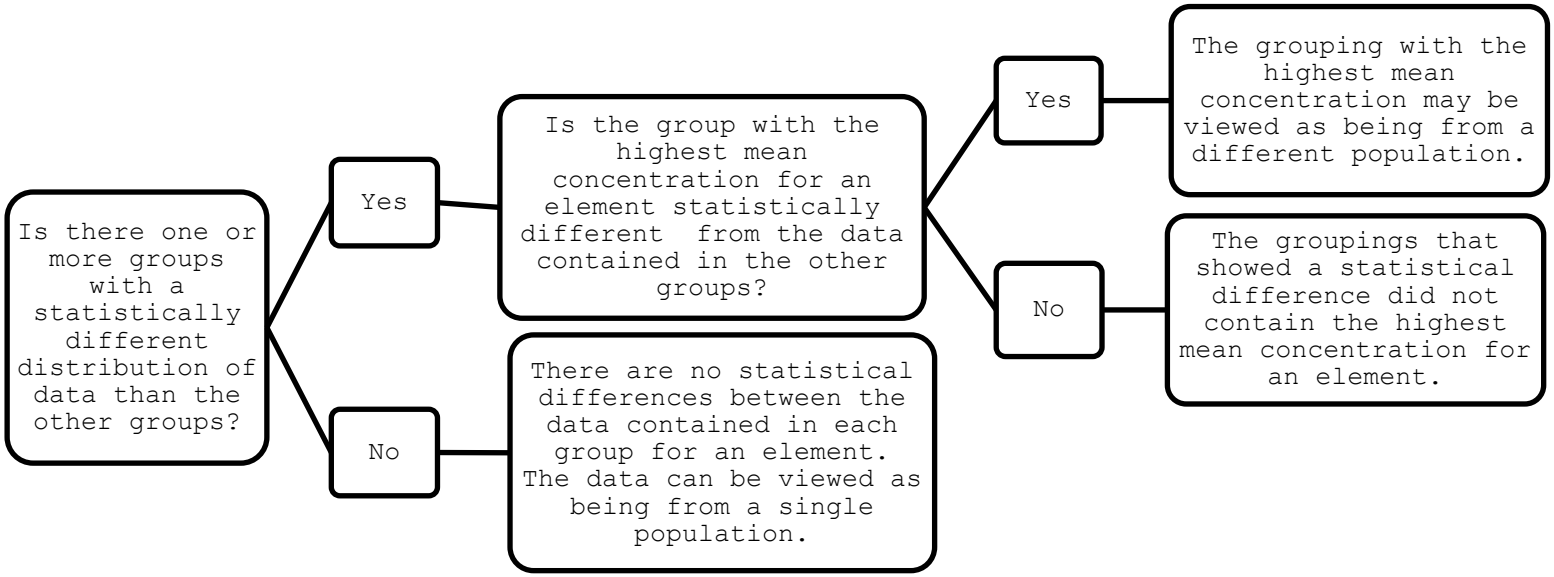

Figure 9: Logic used to determine if the locations of interest may contain elevated concentrations of contaminants.

3. RESULTS & DISCUSSION

The quality control results (Tables 7 and 8) and the analysis results (Tables 9, 10 and 11) can be found in Appendix C. The quality control results were used to validate the sampling plan and laboratory preparation and analysis process. The results were checked against the data quality objectives (pages 28-29 and page 38-39), and only one data point failed to meet the required criteria. This was the Ag result for the SMPD, which was 36.4% above the expected value. However, at the low concentrations of Ag found in the sample and SMPD, the expanded uncertainty at the 95% confidence level is 47.7%, which is the likely cause of an RPD above 30%. There is an allowance for this scenario in the PAMEPA (MOECC, 2011c), if the sample and duplicate result is less than five times the method detection limit. Since the method detection limit for Ag is 0.03 mg/kg, and five times the method detection limit is 0.15 mg/kg, both the sample and SMPD results of 0.09 and 0.13 mg/kg respectively, are acceptable. Another item to note is that the EB contained results for Ba, Ni and Zn that were slightly above the method detection limit.

From the analysis results, the mean concentration of each element was calculated after removing outliers at the 95% confidence level, and compared to the SSEPA limits found in Table 2 on page 46. This was performed to answer research objective #1 and #2, and shows that contaminant concentrations are within the acceptable range of background concentrations for Ontario as defined in SSEPA Table 1. Contaminant concentrations are also below the threshold values in SSEPA Table 3, which were developed to protect the health of humans and the environment (MOECC, 2011a).

Element	Project Results Mean (mg/kg)	Uncertainty at the 95% confidence level (mg/kg)	SSEPA Table 1 *Background Values* (mg/kg)	SSEPA Table 3 *Protection of Human Health & Environment* (mg/kg)
Ag	0.06	0.03	0.5	40
As	4.31	0.67	18	18
Ba	113	17	220	670
Be	1	0.1	2.5	8
Cd	<0.5	NA	1.2	1.9
Co	10.7	2.1	21	80
Cr	17.3	0.1	70	160
Cu	27.9	0.7	92	230
Hg	0.13	0.1	0.27	3.9
Mo	<1.2	NA	2	40
Ni	21.5	2	82	270
Pb	40.5	10	120	120
Sb	0.09	0.01	1.3	40
Se	<0.40	NA	1.5	5.5
Tl	0.34	0.04	1	3.3
U	1.57	0.16	2.5	33
V	35.1	4	86	86
Zn	94	8	290	340

Table 2: Project results compared to SSEPA values (MOECC, 2011b). The mean concentration was calculated for each element from the entire dataset, after the removal of outliers. For Hg, the two values above detection were used to calculate the average, to provide a conservative comparison. This is the most relevant table because it shows that the mean concentration for every element is below regulatory limits. The mean concentrations can also be used as background values for the site.

The locations of interest and the systematic grid samples were then compared as separate groups to answer research objective #3. The mean concentration for each element in each group is presented in Table 3 (page 47), with Tables 4 and 5 (page 48) revealing the results from the ANOVA. From the ANOVA, Figure 10 depicts the frequency that a group contains the

maximum mean concentration for an element, and the frequency that a group contains an outlier at the maximum side of the distribution.

I.D	Ag mg/kg	+/-	As mg/kg	+/-	Ba mg/kg	+/-	Be mg/kg	+/-	Cd mg/kg	+/-	Co mg/kg	+/-
1 AVG	0.09	0.05	3.52	0.55	118	17	0.7	0.1	<0.5	NA	10.6	2.1
2 AVG	0.08	0.04	4.48	0.7	111	16	1	0.1	<0.5	NA	12.3	2.4
3 AVG	0.06	0.03	4.52	0.71	108	16	1	0.1	<0.5	NA	10.5	2.1
4 AVG	0.05	0.02	5.12	0.8	97	14.2	1	0.2	<0.5	NA	11.1	2.2
5 AVG	0.06	0.03	4.02	0.63	115	17	0.9	0.1	<0.5	NA	10.4	2
I.D	**Cr mg/kg**	**+/-**	**Cu mg/kg**	**+/-**	**Hg mg/kg**	**+/-**	**Mo mg/kg**	**+/-**	**Ni mg/kg**	**+/-**	**Pb mg/kg**	**+/-**
1 AVG	14.3	2.4	27	2.4	<0.10	NA	<1.2	NA	17.1	1.6	36.8	9.1
2 AVG	20	3.3	29.9	2.7	<0.10	NA	<1.2	NA	22.1	2	44.1	10.9
3 AVG	19.3	3.2	29.7	2.7	NA	NA	<1.2	NA	25.6	2.3	38.5	9.5
4 AVG	19.2	3.2	30	2.7	NA	NA	<1.2	NA	30.2	2.7	39.3	9.8
5 AVG	15.8	2.6	26.1	2.3	<0.10	NA	<1.2	NA	19.3	1.8	41.9	10.4
I.D	**Sb mg/kg**	**+/-**	**Se mg/kg**	**+/-**	**Tl mg/kg**	**+/-**	**U mg/kg**	**+/-**	**V mg/kg**	**+/-**	**Zn mg/kg**	**+/-**
1 AVG	0.12	0.02	<0.40	NA	0.31	0.03	1.44	0.15	31.2	3.5	90.7	7.6
2 AVG	0.1	0.02	<0.40	NA	0.38	0.04	1.74	0.17	37.9	4.3	106	9
3 AVG	0.08	0.01	<0.40	NA	0.35	0.04	1.62	0.16	35.6	4.1	96.6	8.3
4 AVG	0.07	0.01	<0.40	NA	0.35	0.04	1.75	0.18	36.7	4.2	95.9	8.2
5 AVG	0.08	0.01	<0.40	NA	0.33	0.03	1.49	0.15	34.7	4	94.1	8

Table 3: The average concentration of elements in each grouping, after removing the outliers from each group. The highest average concentration for each element is shown in red.

Element	F	F crit	F/F Crit	p-value	p-value < 0.05
Ag	1.24	2.74	0.5	3.20E-01	No
As	11	2.78	4	3.21E-05	Yes
Ba	5.27	2.74	1.9	3.04E-03	Yes
Be	10.3	2.76	3.7	4.56E-05	Yes
Co	1.32	2.73	0.5	2.89E-01	No
Cr	10.2	2.73	3.7	3.63E-05	Yes
Cu	7.09	2.76	2.6	5.85E-04	Yes
Ni	18.9	2.73	6.9	1.67E-07	Yes
Pb	2.01	2.74	0.7	1.22E-01	No
Sb	9.01	2.6	3.5	5.38E-05	Yes
Tl	2.86	2.73	1	4.25E-02	Yes
U	16.2	2.74	5.9	8.95E-07	Yes
V	5.18	2.73	1.9	3.14E-03	Yes
Zn	1.31	2.74	0.5	2.94E-01	No

Table 4: An ANOVA used to determine if there is a statistically significant difference in the mean concentration values between groups for an element. If the p-value is less than 0.05, the element of interest will be investigated further to determine if the grouping with the highest mean concentration may be part of a statistically different group than the other samples.

Element	F	F crit	F/F Crit	p-value	p-value < 0.05
As	13.94	4.21	3.3	8.91E-04	Yes
Ba	6.78	4.18	1.6	1.44E-02	Yes
Be	7.03	4.2	1.7	1.30E-02	Yes
Cr	6.51	4.17	1.6	1.60E-02	Yes
Cu	3.64	4.2	0.9	6.65E-02	No
Ni	26.9	4.17	6.5	1.38E-05	Yes
Sb	21.8	4.18	5.2	6.28E-05	Yes
Tl	6.11	4.17	1.5	1.94E-02	Yes
U	8.59	4.18	2.1	6.53E-03	Yes
V	3.64	4.2	0.9	6.65E-02	No

Table 5: ANOVA results used to determine if the grouping with the highest mean concentration for an element may be part of a statistically different group, as compared to the entire dataset.

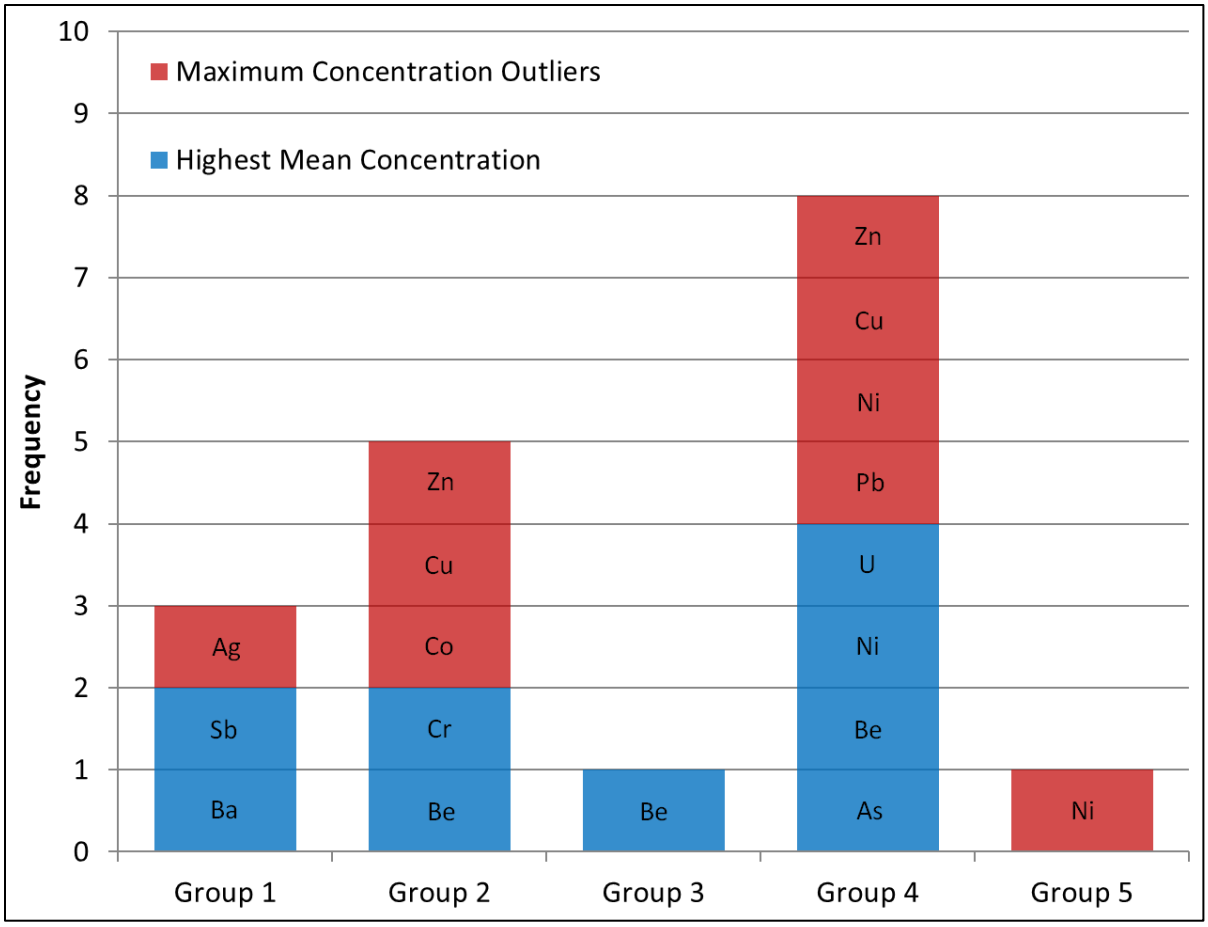

Figure 10: Frequency of elements per sampling group. The chart displays the number of times each group; (a) had the highest mean concentration for an element that was statistically significant (blue), and (b) contained an outlier that was outside the 95% confidence level on the maximum side of the distribution, derived from all of the data points for an element (red).

Figure 10 shows that maximum mean concentrations values are found in the locations of interest and seven of ten maximum outliers are found in groups 2 and 4. However, while statistical tools are useful to delineate contaminated areas (CCME, 2016), in this specific data set, one must be careful to make too many inferences based upon the ANOVA. The groups that contain the highest mean concentration values for an element are still well below the SSEPA set limits. Furthermore, in group 4 for instance, which

contains the highest mean concentration value for U, the U concentration is only 0.6% higher than the next highest mean concentration value. Practically, when taking uncertainty into consideration, the concentration values of 1.74 mg/kg and 1.75 mg/kg are the same, and the results of the ANOVA are not significant, and may be caused by a Type I error. This is also the case for Be.

The maximum concentration outliers (Table 6) do reveal some insights however, as they are likely caused by small amounts of element rich material being sub-sampled and analyzed. The Pb outlier in grouping 4 for instance, may have been caused by dust from the 5000 kg of Pb being transferred for disposal, in and around location 4, during the legacy waste disposal initiative at the laboratory. There was one outlier that exceeded the guideline limits, which was the Cu concentration from sampling point 4E. The value of 555 mg/kg is 2.4 times the SSEPA Table 3 limit of 230 mg/kg. Again, this result is likely caused by a small amount of Cu finding its way into the sub-sample for analysis, as copper piping from the renovation was sorted prior to disposal in location 4. Despite these inferences, one must not dismiss the notion that the outliers may also be caused by analytical error.

Sampling Point	Element	mg/kg	+/-
1E	Ag	0.21	0.10
2B	Co	16.5	1.7
2B	Cu	52.1	4.7
2C	Zn	146	12
4A	As	11.6	1.8
4A	Pb	71.8	17.8
4B	Ni	39	3.6
4E	Cu	555	49.7
4E	Zn	223	19.0
6e	Ni	36.6	3.3

Table 6 – Outliers that are outside the 95% confidence level on the maximum side of the distribution, derived from the entire dataset for an element.

4. CONCLUSIONS & RECOMMENDATIONS

The results verify that the concentrations of Ag, As, Ba, Be, Cd, Co, Cr, Cu, Hg, Mo, Ni, Pb, Sb, Se, Sn, Tl, U, V and Zn in soil at the laboratory are within the background values for Ontario, as listed in the SSEPA (Table 8). The elements of interest are also well below guideline values in SSEPA Table 3 (Table 8) for the protection of human health and the environment. While the results from the locations of interest reveal that there may be statistical differences in the maximum mean concentrations for As, Ba, Be, Cr, Ni, Sb and U, the practical significance of the statistical analysis is limited, because analyte concentrations are low compared to the limits in the SSEPA, and are comparable to the systematic grid samples in grouping 5 (Table 9). Therefore, the mean concentration for each element, after the removal of outliers (Table 8), can thus be used as the baseline for future monitoring purposes.

The outliers (Table 11) are of interest, in Waste Collection Area #1 and Hazardous Waste Transfer Location #2, as Co, Cu, Ni, Pb and Zn were constituents of the waste disposed of the renovation and legacy disposal initiative. It is plausible, that small particles of these metals, from copper pipes and galvanized screws for instance, can be found in the soil. A minor recommendation would be to improve operational practices during renovation and waste disposal activities by ensuring that tarps are used to cover the soil, if waste is temporarily handled and stored in large quantities. Alternatively, the company can prevent workers from using the soil as temporary storage altogether, by organizing a more frequent collection of waste when needed.

As a result of this project, employees that were previously unsure about levels of soil contamination, have empirical evidence that the facility is not contaminated with the elements analyzed (Table 11) (MOECC, 2011a). The company has also closed a gap in its environmental monitoring program, as the following components from Figure 1, have now been accounted for. These are the S2, S3, S-Outside Air, S-Nose, Mammals & Birds, and, Plants & Soil Invertebrates. This covers outdoor exposures to a contaminant for humans, animals and organisms, but does not directly provide exposure information for workers inside the building, as sub-surface soils were not tested. It is unlikely however, that significant quantities of the metals and metalloids analyzed in this project, would enter the breathing air inside the building in significant quantities from the soil (MOECC, 2011a). And since the groundwater testing in 2016, had only one result above background concentrations for Zn in groundwater, if contaminants do exist in sub-surface soils, they are not appreciably leaching into the groundwater. A last minor recommendation and possible future work, would be to sample and analyze the organic compounds listed in SSEPA Table 1 and 3. The site reconnaissance and sampling plan from this project can be used to perform this task, in consultation with the PAMEPA, which outlines the sampling requirements for semi-volatile and volatile compounds. Since there are only minor recommendations, and the results are below SSEPA Table 1 guidelines for the analytes tested, this project shows that the health of humans and the environment are being protected, and the soil is being maintained as an essentially non-renewable resource (MOECC, 2011a).

APPENDIX A: Summary of Elements in terms of their Toxicity to Humans (page 1 of 4)

Element	Ag	As	B	Ba	Be
Essentiality to Human Health	No	No	No	No	No
CCME Limit for Industry (mg/kg)	40	12	2	2000	8
Exposure Pathways:	I, G, DC	I, G	I, G	I, G	I, G
Inhalation	Minimal exposure, except in workplace	Enters bloodstream via lungs	Enters bloodstream via lungs	Enters bloodstream	Enters bloodstream
Ingestion	Via contamination, absorbed in mouth throat and digestive tract	Inorganic As primary concern, as elemental As is poorly absorbed. Enters bloodstream	Enters bloodstream	Enters bloodstream	Enters bloodstream via digestive tract (<1%)
Excretion	Feces, urine, 1 week	Urine, days-years	Urine, 24 hours-4 days	Feces and urine, 1-2 weeks	Ingested Be via feces; absorbed Be via urine
Target Organs	Throughout body	Liver, kidneys, lungs, spleen and skin**	Intestines, liver, kidneys and brain	Heart, stomach, lungs	Lungs, Liver, Bones
Health Effects	Dermal reactions including argyria; respiratory, and digestive tract irritation;	Circulation and nervous disorders, irritation of stomach, intestines, throat, lungs, death	Short term irritation of nose, throat and eyes. Stomach, intestines, liver, kidney and brain impairment, death	Digestive tract irritation, respiratory irritation, blood pressure, heart rhythm, paralysis, death	Lung damage, pneumonia, acute beryllium disease, Be sensitivities causing granulomas and chronic beryllium disease, fatal
Carcinogenicity*	Not classified	Group 1 –(Inorganic As)	Not classified	Not classified	Group 1

Key: I – Inhalation, G- Ingestion, DC- Direct Contact

APPENDIX A (continued): Summary of Elements in terms of their Toxicity to Humans (page 2 of 4)

Element	Cd	Co	Cr	Cu	Hg
Essentiality to Human Health	No	Yes	Yes	Yes	No
CCME Limit for Industry (mg/kg)	22	300	87	91	50
Exposure Pathways:	I, G	I, G	I, G	I, G	I, G, DC
Inhalation	Enters bloodstream via lungs (5-50%)	Absorption via lungs dependent on Co particle size	Enters bloodstream via lungs	Commonly attached to dust and dirt; increase exposure at workplaces	Enters the bloodstream (80%)
Ingestion	Enters bloodstream via digestive tract (1-10%)	Absorption increases if iron levels are low	Enters body via digestive tract (small percentage)	Absorption dependent on amount in body prior to ingestion	Absorption depends on species: methylmercury (95%), inorganic Hg (50%), metallic Hg (<0.01%)
Excretion	Absorbed Cd via urine and feces; non-absorbed via feces	Insoluble and unabsorbed Co via feces; absorbed Co via urine	Mostly via urine, 1 week. Can remain in body for several years	Feces and urine,; days	Urine, feces and exhalation; weeks-months
Target Organs	Lungs, stomach, remains in kidneys and liver for many years	Throughout body; concentrates in liver, kidneys and bones	Lungs	Liver and kidneys	Brain, kidneys, stomach
Health Effects	GI system irritation, kidney disease, fragile bones, lung cancer, death	Respiratory irritation, including asthma, pneumonia, and wheezing. Co allergy-causing dermal reactions. GI system irritation, heart disorders, death	Respiratory irritation; Cr allergy- breathing disorders, dermal reactions; GI System irritations including ulcers	Irritation of respiratory and GI systems, irritation to eyes and causes headaches. Liver and kidney damage leading to death	Damage to nervous, GI, renal and respiratory systems, irritability, memory, sensation and vision loss, tremors
Carcinogenicity*	Group 1	Group 2B	Group 1 (Cr (VI))	Not classified	Not Classified; Mercury chloride and methylmercury possible carcinogens

APPENDIX A (continued): Summary of Elements in terms of their Toxicity to Humans (page 3 of 4)

Element	Mo	Ni	Pb	Sb	Se
Essentiality to Human Health	Yes	Yes	No	No	Yes
CCME Limit for Industry (mg/kg)	50	89	600	40	2.9
Exposure Pathways:	I, G	I,G	I, G, DC	I, G	I, G
Inhalation	Enters bloodstream and remains in lungs	Enters bloodstream, amount depends on particle size	Small particles enter bloodstream, large particles are coughed up	Enters bloodstream via lungs	Inhalation not common, except in workplace conditions
Ingestion	Recommended intake of 45 ug/day	Absorbed more effectively from water than food	Amount dependent whether person has consumed food recently (ranges from 6% to 60-80%)	Enters bloodstream	Both inorganic and organic species are absorbed
Excretion	Urine	Absorbed via urine; ingested via feces	Mostly excreted within weeks (99%). Accumulates in body with chronic exposure.	Feces and urine, weeks	Urine, feces, exhalation, 24 hours
Target Organs	Throughout body, liver, kidneys	Throughout body, mainly kidneys	Liver, kidneys, lungs, brain, spleen, heart, muscles, bones and teeth	Throughout body; highest amounts in blood, spleen, liver and kidneys	Liver, kidneys, blood, lungs, testes, nails, hair
Health Effects	Damage to respiratory system. Damage to renal system, and reproductive system in high amounts	Allergic reaction, sensitivities; damage to blood and kidneys, damage to respiratory system, including cancer; death	Nervous and reproductive system damage, increase in blood pressure, brain and kidney damage, death, weakness in fingers, wrists, and ankles	Damage to heart and GI system	Dizziness, fatigue, irritation of mucous membranes, brittle hair, deformed nails, loss of feeling in arms and legs; respiratory damage
Carcinogenicity*	Not classified	Group 1 (Ni compounds); Group 2B (Metallic Ni and Ni alloys)	Group 2A (Inorganic Pb); Not classified (Organic Pb)	Group 2B (Sb_2O_3); Group 3 (Sb_2S_3)	Group 3; Selenium sulfide possible carcinogen

APPENDIX A (continued): Summary of Elements in terms of their Toxicity to Humans (page 4 of 4)

Element	Sn	Tl	U	V	Zn
Essentiality to Human Health	No	No	No	No	Yes
CCME Limit for Industry (mg/kg)	300	1	300	130	360
Exposure Pathways:	I, G	I, G	I, G	1, G	I, G
Inhalation	Inorganic tin compounds contribute to stannic oxide deposits; organic compounds may lead to requiring artificial ventilation***	Minimal exposure via inhalation	Enters bloodstream (0.76-5%)	Percentage absorbed via lungs unknown	Minimal exposure, except in workplace
Ingestion	Very little enters via ingestion	Mostly absorbed	Enters bloodstream (0.1-6%)	Enters bloodstream (3-20%)	Recommended daily allowance is 11 mg/day (men) and 8 mg/day (women)
Excretion	Feces, urine; weeks-months	Urine, feces; hours-months	Inhaled and ingested via feces; absorbed via urine; weeks-months	Feces, Urine	Urine, feces
Target Organs	Throughout the body; bones, lungs	Throughout body; kidneys and liver, heart, lungs	Throughout body; kidneys, bones, liver	Lungs***	Throughout body; blood and bones
Health Effects	Skin and eye irritation, anemia, irritation/damage of GI, respiratory (pneumoconiosis), neurological and renal systems, death	Irritation/damage to nervous, circulatory, renal, and GI systems. Hair loss, death	Respiratory system and kidney damage	GI system irritation, coughing	Metal fume fever, GI system irritation, damage to pancreas, affects cholesterol
Carcinogenicity*	Not Classified	Not Classified	Not Classified	Group 2B	Not Classified

References: All data is from ATSDR, 2017 & 2018, unless otherwise stated as noted below:

(*IARC, 2017 & 2018; **CCME, 2017, ***Waters, 1977)

APPENDIX B: Toronto Municipal Code Chapter 681, Sewers, Table 1 (City of Toronto, 2016)

Table 1 – Limits for Sanitary and Combined Sewers Discharge
[Amended 2002-10-31 by By-law No. 855-2002; 2010-07-08 by By-law No. 868-2010; 2016-02-04 by By-law No. 100-2016]

Parameter	Limit	Unit	Parameter	Limit	Unit
pH	>6.0 to < 11.5	SU	1,1,2,2- tetrachloroethane	1.4	mg/L^3
Temperature	< 60	Degrees Celsius	1,2-dichlorobenzene	0.05	mg/L^3
Biochemical oxygen demand	300	mg/L^3	1,4-dichlorobenzene	0.08	mg/L^3
Cyanide (total)	2	mg/L^3	3,3'-dichlorobenzidine	0.002	mg/L^3
Fluoride	10	mg/L^3	Benzene	0.01	mg/L^3
Total Kjeldahl Nitrogen	100	mg/L^3	Bis (2-ethylhexyl) phthalate	0.012	mg/L^3
Oil and grease - animal and vegetable (non-mineral)[1]	150	mg/L^3	Chloroform	0.04	mg/L^3
Oil and grease - mineral and synthetic	15	mg/L^3	Cis-1,2-dichloroethylene	4	mg/L^3
Phenolics (4AAP)	1.0	mg/L^3	Di-n-butyl phthalate	0.08	mg/L^3
Phosphorus (total)	10	mg/L^3	Ethyl benzene	0.16	mg/L^3
Suspended solids (total)	350	mg/L^3	Methylene chloride	2	mg/L^3
Aluminum (total)	50	mg/L^3	Nonylphenols	0.02	mg/L^3
Antimony (total)	5	mg/L^3	Nonylphenol ethoxylates[2]	0.2	mg/L^3
Arsenic (total)	1	mg/L^3	PCBs	0.001	mg/L^3
Cadmium (total)	0.7	mg/L^3	Pentachlorophenol	0.005	mg/L^3
Chromium (hexavalent)	2	mg/L^3	Tetrachloroethylene	1	mg/L^3
Chromium (total)	4	mg/L^3	Toluene	0.016	mg/L^3
Cobalt (total)	5	mg/L^3	Total PAHs[2]	0.005	mg/L^3
Copper (total)	2	mg/L^3	Trans-1,3-dichloropropylene	0.14	mg/L^3
Lead (total)	1	mg/L^3	Trichloroethylene	0.4	mg/L^3
Manganese (total)	5	mg/L^3	Xylenes (total)[2]	1.4	mg/L^3
Mercury (total)	0.01	mg/L^3			
Molybdenum (total)	5	mg/L^3			
Nickel (total)	2	mg/L^3			
Selenium (total)	1	mg/L^3			
Silver (total)	5	mg/L^3			
Tin (total)	5	mg/L^3			
Titanium (total)	5	mg/L^3			
Zinc (total)	2	mg/L^3			

Footnote 1: The noted parameter is calculated.
Footnote 2: The noted parameters have calculated totals.
Footnote 3: mg/L is expressed in milligrams per litre.

APPENDIX C: Results and Data Analysis Tables

I.D	Ag mg/kg	+/-	As mg/kg	+/-	Ba mg/kg	+/-	Be mg/kg	+/-	Cd mg/kg	+/-	Co mg/kg	+/-	Cr mg/kg	+/-	Cu mg/kg	+/-	Hg mg/kg	+/-
EB	<0.0001	NA	<0.0001	NA	0.006	0.005	<0.002	NA	<0.002	NA	<0.005	NA	<0.005	NA	<0.005	NA	<0.0001	NA
FB#1	<0.0001	NA	<0.0001	NA	<0.002	NA	<0.002	NA	<0.002	NA	<0.005	NA	<0.005	NA	<0.005	NA	<0.0001	NA
FB#2	<0.0001	NA	<0.0001	NA	<0.002	NA	<0.002	NA	<0.002	NA	<0.005	NA	<0.005	NA	<0.005	NA	<0.0001	NA
TB#1	<0.0001	NA	<0.0001	NA	<0.002	NA	<0.002	NA	<0.002	NA	<0.005	NA	<0.005	NA	<0.005	NA	<0.0001	NA
TB#2	<0.0001	NA	<0.0001	NA	<0.002	NA	<0.002	NA	<0.002	NA	<0.005	NA	<0.005	NA	<0.005	NA	<0.0001	NA
MB#1	<0.024	NA	<0.03	NA	<0.5	NA	<0.5	NA	<0.5	NA	<1.2	NA	<1.2	NA	<1.2	NA	<0.10	NA
MB#2	<0.024	NA	<0.03	NA	<0.5	NA	<0.5	NA	<0.5	NA	<1.2	NA	<1.2	NA	<1.2	NA	<0.10	NA
SMPD (Sample 2)	0.13	0.06	4.21	0.66	110	16	1.1	0.2	<0.5	NA	11.6	2.3	19.7	3.3	27.4	2.5	<0.10	NA
SMPD RPD	36.4	NA	-7.32	NA	-0.9	NA	9.5	NA	NA	NA	-12.1	NA	9.6	NA	-1.1	NA	NA	NA
MXS	1.47	0.70	19.3	3.01	905	134	440	63	427	61	486	95	517	86	577	52	1.03	0.07
MXS Expected	1.53	NA	19.3	NA	919	NA	478	NA	479	NA	526	NA	546	NA	585	NA	1.04	NA
MXS Recovery	96.1	NA	100	NA	98.5	NA	92.1	NA	89.1	NA	92.4	NA	94.7	NA	98.6	NA	99.0	NA
CRM #1	5.02	0.50	4.99	0.55	195	19	0.9	0.1	44.8	6.4	9.0	0.6	15.9	1.7	129	10.4	7.10	0.51
CRM #2	5.23	0.52	5.22	0.58	197	20	0.9	0.1	46.4	6.6	8.1	0.6	15.8	1.7	129	10.4	7.80	0.56
CRM #3	4.78	0.48	5.04	0.56	195	19	0.9	0.1	44.4	6.3	8.3	0.6	16.2	1.7	122	9.8	7.28	0.52
CRM Expected	5.5	NA	4.9	NA	190	NA	0.9	NA	47	NA	7.5	NA	15	NA	130	NA	7.40	NA
CRM #1 Recovery	91.3	NA	102	NA	103	NA	100	NA	95.3	NA	120	NA	106	NA	99.2	NA	95.9	NA
CRM #2 Recovery	95.1	NA	107	NA	104	NA	100	NA	98.7	NA	6.8	NA	105	NA	99.2	NA	105	NA
CRM #3 Recovery	86.9	NA	103	NA	103	NA	100	NA	94.5	NA	122	NA	108	NA	93.8	NA	98.4	NA
LCS #1	1.20	0.04	1.26	0.03	125	3	120	3	121	3	125	2	119	5	127	5	1.23	0.03
LCS Expected #1	1.23	NA	1.23	NA	123	NA	123	NA	123	NA	123	NA	123	NA	123	NA	1.23	NA
LCS Recovery #1	97.60	NA	102	NA	102	NA	97.6	NA	98.4	NA	102	NA	96.7	NA	103	NA	100	NA
LCS #2	1.24	0.04	1.22	0.03	122	3	120	3	123	3	122	2	123	5	125	5	1.23	0.03
LCS Expected #2	1.23	NA	1.23	NA	123	NA	123	NA	123	NA	123	NA	123	NA	123	NA	1.23	NA
LCS Recovery #2	101	NA	99.2	NA	99.2	NA	97.6	NA	100	NA	99.2	NA	100	NA	102	NA	100	NA

Table 7: Quality control data for Ag, As, Ba, Be, Cd, Co, Cr, Cu and Hg. Results for all quality control samples are within the specifications found in the PAMEPA.

I.D	Mo mg/kg	+/-	Ni mg/kg	+/-	Pb mg/kg	+/-	Sb mg/kg	+/-	Se mg/kg	+/-	Tl mg/kg	+/-	U mg/kg	+/-	V mg/kg	+/-	Zn mg/kg	+/-
EB	<0.005	NA	0.008	0.004	<0.01	NA	<0.0001	NA	<0.001	NA	<0.0001	NA	<0.0001	NA	<0.005	NA	0.005	0.005
FB#1	<0.005	NA	<0.005	NA	<0.01	NA	<0.0001	NA	<0.001	NA	<0.0001	NA	<0.0001	NA	<0.005	NA	<0.003	NA
FB#2	<0.005	NA	<0.005	NA	<0.01	NA	<0.0001	NA	<0.001	NA	<0.0001	NA	<0.0001	NA	<0.005	NA	<0.003	NA
TB#1	<0.005	NA	<0.005	NA	<0.01	NA	<0.0001	NA	<0.001	NA	<0.0001	NA	<0.0001	NA	<0.005	NA	<0.003	NA
TB#2	<0.005	NA	<0.005	NA	<0.01	NA	<0.0001	NA	<0.001	NA	<0.0001	NA	<0.0001	NA	<0.005	NA	<0.003	NA
MB#1	<1.2	NA	<1.2	NA	<2.4	NA	<0.024	NA	<0.40	NA	<0.024	NA	<0.024	NA	<1.2	NA	<0.5	NA
MB#2	<1.2	NA	<1.2	NA	<2.4	NA	<0.024	NA	<0.40	NA	<0.024	NA	<0.024	NA	<1.2	NA	<0.5	NA
SMPD	<1.2	NA	22.2	2.0	44.8	11.1	0.09	0.02	<0.40	NA	0.41	0.04	1.85	0.19	39.9	4.5	93.1	7.8
SMPD RPD %	NA	NA	1.8	NA	13.3	NA	-10.5	NA	NA	NA	7.59	NA	6.13	NA	4.1	NA	-1.2	NA
MXS	436	96	519	47	633	157	1.53	0.28	1.14	0.22	2.66	0.28	8.11	0.81	618	71	787	66
MXS Expected	474	NA	561	NA	631	NA	1.57	NA	1.18	NA	2.71	NA	8.15	NA	627	NA	851	NA
MXS Recovery %	92	NA	92.5	NA	100	NA	97.5	NA	96.6	NA	98.2	NA	99.5	NA	98.6	NA	92.5	NA
CRM #1	2.2	0.5	15.5	1.2	1260	76	4.56	0.37	2.03	0.39	1.86	0.14	1.76	0.14	30.3	3.4	338	26.0
CRM #2	2.5	0.6	15.9	1.3	1280	77	4.59	0.37	1.55	0.30	1.92	0.14	1.84	0.15	30.4	3.4	340	27.0
CRM #3	1.8	0.4	14.9	1.2	1220	73	4.47	0.36	1.46	0.28	1.90	0.14	2.02	0.16	30.3	3.4	330	26.0
CRM Expected %	NA	NA	15	NA	1300	NA	4.9	NA	1.7	NA	2.10	NA	NA	NA	28	NA	350	NA
CRM #1 Recovery %	NA	NA	103	NA	96.9	NA	93.1	NA	119	NA	88.6	NA	NA	NA	108	NA	96.6	NA
CRM #2 Recovery %	NA	NA	106	NA	98.5	NA	93.7	NA	91.2	NA	91.4	NA	NA	NA	109	NA	97.1	NA
CRM #3 Recovery %	NA	NA	99.3	NA	93.8	NA	91.2	NA	85.9	NA	90.5	NA	NA	NA	108	NA	94.3	NA
LCS #1	124	4	120	3	116	7	1.26	0.03	1.20	0.04	1.18	0.05	1.17	0.07	121	2	125	3
LCS Expected #1	123	NA	123	NA	123	NA	1.23	NA	1.23	NA	1.23	NA	1.23	NA	123	NA	123	NA
LCS Recovery #1 %	101	NA	97.6	NA	94.3	NA	102	NA	97.6	NA	95.9	NA	95.1	NA	98.4	NA	102	NA
LCS #2	119	4	125	4	124	8	1.24	0.03	1.22	0.04	1.23	0.06	1.22	0.07	124	2	124	3
LCS Expected #2	123	NA	123	NA	123	NA	1.23	NA	1.23	NA	1.23	NA	1.23	NA	123	NA	123	NA
LCS Recovery #2 %	96.7	NA	102	NA	101	NA	101	NA	99.2	NA	100	NA	99.2	NA	101	NA	101	NA

Table 8: Quality control data for Mo, Ni, Pb, Sb, Se, Tl, U, V and Zn. Results for all quality control samples are within the specifications found in the PAMEPA.

I.D	Ag mg/kg	+/-	As mg/kg	+/-	Ba mg/kg	+/-	Be mg/kg	+/-	Cd mg/kg	+/-	Co mg/kg	+/-	Cr mg/kg	+/-	Cu mg/kg	+/-	Hg mg/kg	+/-
1A	0.04	0.02	3.50	0.55	111	16	0.5	0.1	<0.5	NA	11.9	2.3	16.0	2.7	26.3	2.4	<0.10	NA
1B	<0.03	NA	3.60	0.56	128	19	<0.5	NA	<0.5	NA	9.7	1.9	14.6	2.4	31.0	2.8	<0.10	NA
1C	0.08	0.04	3.53	0.55	115	17	<0.5	NA	<0.5	NA	9.5	1.9	14.3	2.4	25.7	2.3	<0.10	NA
1D	0.04	0.02	4.41	0.69	120	18	0.8	0.1	<0.5	NA	12.9	2.5	13.0	2.2	24.4	2.2	<0.10	NA
1E	0.21	0.10	3.46	0.54	117	17	0.8	0.1	<0.5	NA	8.9	1.7	13.7	2.3	27.4	2.5	<0.10	NA
2A	0.09	0.04	4.53	0.71	111	16	1.0	0.1	<0.5	NA	13.1	2.6	17.9	3.0	27.7	2.5	<0.10	NA
2B	0.07	0.03	4.29	0.67	110	16	1.0	0.1	<0.5	NA	16.5	3.2	24.1	4.0	52.1	4.7	<0.10	NA
2C	0.08	0.04	4.66	0.73	112	17	1.0	0.1	<0.5	NA	11.6	2.3	17.7	2.9	32.7	2.9	<0.10	NA
2D	0.08	0.04	4.55	0.71	111	16	0.9	0.1	<0.5	NA	10.4	2.0	23.2	3.8	29.3	2.6	<0.10	NA
2E	0.07	0.03	4.38	0.68	113	17	1.0	0	<0.5	NA	10.0	2.0	16.9	2.8	29.8	2.7	<0.10	NA
3A	0.06	0.03	3.76	0.59	106	16	0.9	0.1	<0.5	NA	11.6	2.3	16.8	2.8	32.2	2.9	<0.10	NA
3B	0.05	0.02	3.84	0.60	103	15	0.9	0.1	<0.5	NA	12.8	2.5	22.3	3.7	27.5	2.5	<0.10	NA
3C	0.04	0.02	4.32	0.67	110	16	1.0	0.1	<0.5	NA	9.7	1.9	17.6	2.9	29.4	2.6	<0.10	NA
3D	0.09	0.04	5.30	0.83	110	16	1.0	0.1	<0.5	NA	9.2	1.8	18.7	3.1	29.6	2.7	0.12	0.10
3E	0.05	0.02	5.39	0.84	109	16	1.0	0.1	<0.5	NA	9.1	1.8	20.9	3.5	30.0	2.7	<0.10	NA
4A	0.04	0.02	11.6	1.8	45.5	7.0	1.0	0.1	<0.5	NA	12.0	2.3	19.2	3.2	30.2	2.7	<0.10	NA
4B	0.05	0.02	5.22	0.81	109	16	0.9	0.1	<0.5	NA	10.6	2.1	17.1	2.8	30.5	2.7	0.13	0.1
4C	0.03	0.01	5.14	0.80	109	16	1.1	0.2	<0.5	NA	11.9	2.3	19.2	3.2	29.5	2.6	<0.10	NA
4D	0.05	0.02	5.02	0.78	117	17	1.1	0.2	<0.5	NA	10.3	2	21.9	3.6	29.6	2.7	<0.10	NA
4E	0.10	0.05	5.08	0.79	102	15	1.1	0.2	<0.5	NA	10.5	2.1	18.4	3.0	555	50	<0.10	NA

Table 9: Sample results for Ag, As, Ba, Be, Cd, Co, Cr, Cu and Hg at the critical locations. Outliers are represented in red.

I.D	Mo mg/kg	+/-	Ni mg/kg	+/-	Pb mg/kg	+/-	Sb mg/kg	+/-	Se mg/kg	+/-	Tl mg/kg	+/-	U mg/kg	+/-	V mg/kg	+/-	Zn mg/kg	+/-
1A	<1.2	NA	18.6	1.7	29.3	7.3	0.11	0.02	<0.40	NA	0.35	0.04	1.57	0.16	34.6	3.9	84.8	7.1
1B	<1.2	NA	17.3	1.6	42.5	10.5	0.11	0.02	<0.40	NA	0.30	0.03	1.45	0.15	30.9	3.5	96.6	8.1
1C	<1.2	NA	16.1	1.5	33.2	8.2	0.14	0.03	<0.40	NA	0.33	0.03	1.40	0.14	29.3	3.3	86	7.2
1D	<1.2	NA	17.2	1.6	37.2	9.2	0.10	0.02	<0.40	NA	0.29	0.03	1.29	0.13	31.2	3.6	91.4	7.7
1E	<1.2	NA	16.4	1.5	41.7	10.3	0.13	0.02	<0.40	NA	0.28	0.03	1.51	0.15	30.2	3.4	94.8	8.0
2A	<1.2	NA	21.8	2.0	39.2	9.7	0.10	0.02	<0.40	NA	0.38	0.04	1.74	0.17	38.3	4.4	94.2	7.9
2B	<1.2	NA	22.0	2.0	39.7	9.8	0.09	0.02	<0.40	NA	0.4	0.04	1.80	0.18	38.9	4.4	85.6	7.2
2C	<1.2	NA	24.0	2.2	46.7	11.6	0.10	0.02	<0.40	NA	0.38	0.04	1.75	0.18	39.0	4.4	146	12
2D	<1.2	NA	21.8	2.0	48.3	12.0	0.10	0.02	<0.40	NA	0.37	0.04	1.71	0.17	37.4	4.3	100	8
2E	<1.2	NA	21.1	1.9	46.6	11.5	0.12	0.02	<0.40	NA	0.35	0.04	1.68	0.17	36.5	4.2	106	9
3A	<1.2	NA	21.1	1.9	32.7	8.1	0.08	0.01	<0.40	NA	0.36	0.04	1.58	0.16	34.9	4.0	92.0	7.7
3B	<1.2	NA	30.7	2.8	30.3	7.5	0.08	0.01	<0.40	NA	0.36	0.04	1.68	0.17	34.6	3.9	88.7	7.4
3C	<1.2	NA	23.6	2.1	41.6	10.3	0.09	0.02	<0.40	NA	0.33	0.03	1.63	0.16	35.6	4.1	102	9
3D	<1.2	NA	24.5	2.2	41.1	10.2	0.08	0.01	<0.40	NA	0.35	0.04	1.62	0.16	35.8	4.1	102	9
3E	<1.2	NA	27.9	2.5	46.6	11.5	0.08	0.01	<0.40	NA	0.34	0.04	1.57	0.16	36.9	4.2	98.1	8.2
4A	<1.2	NA	28.8	2.6	71.8	17.8	0.06	0.01	<0.40	NA	0.24	0.03	0.81	0.08	29.0	3.3	103	9
4B	<1.2	NA	39.0	3.6	41.6	10.3	0.08	0.01	<0.40	NA	0.36	0.04	1.68	0.17	36.0	4.1	100	8
4C	<1.2	NA	25.3	2.3	33.4	8.3	0.06	0.01	<0.40	NA	0.42	0.04	1.91	0.19	42.7	4.9	79.4	6.7
4D	<1.2	NA	31.2	2.8	44.7	11.1	0.08	0.01	<0.40	NA	0.37	0.04	1.70	0.17	37.9	4.3	101	9
4E	<1.2	NA	26.5	2.4	37.6	9.30	0.08	0.01	<0.40	NA	0.37	0.04	1.71	0.17	38.0	4.3	223	19

Table 10: Sample results for Mo, Ni, Pb, Sb, Se, Tl, U, V and Zn at the critical locations. Outliers are represented in red.

I.D	Ag mg/kg	+/-	As mg/kg	+/-	Ba mg/kg	+/-	Be mg/kg	+/-	Cd mg/kg	+/-	Co mg/kg	+/-	Cr mg/kg	+/-	Cu mg/kg	+/-	Hg mg/kg	+/-
5	0.07	0.03	3.96	0.62	116	17	1.0	0.1	<0.5	NA	10.7	2.1	17.9	3.0	29.3	2.6	<0.10	NA
5R	0.06	0.03	3.42	0.53	119	18	1.0	0.1	<0.5	NA	10.3	2.0	15.6	2.6	26.7	2.4	<0.10	NA
6	0.07	0.03	3.94	0.61	113	17	1.0	0.1	<0.5	NA	10.2	2.0	15.8	2.6	26.0	2.3	<0.1	NA
7	0.04	0.02	5.24	0.82	121	18	0.9	0.1	<0.5	NA	8.7	1.7	14.0	2.3	24.7	2.2	<0.10	NA
7R	0.04	0.02	4.3	0.67	113	17	0.9	0.1	<0.5	NA	8.3	1.6	14.6	2.4	23.6	2.1	<0.10	NA
8	0.05	0.02	4.16	0.65	113	17	1.0	0.1	<0.5	NA	13.5	2.6	16.5	2.7	25.3	2.3	<0.10	NA
9	0.10	0.05	4.48	0.7	118	17	1.0	0.1	<0.5	NA	10.2	2.0	16.3	2.7	27.6	2.5	<0.10	NA
10	0.06	0.03	4.33	0.68	115	17	0.9	0.1	<0.5	NA	10.2	2.0	16.1	2.7	26.3	2.4	<0.10	NA
11	0.08	0.04	3.84	0.6	108	16	0.9	0.1	<0.5	NA	10.7	2.1	16.0	2.7	26.6	2.4	<0.10	NA
12	0.04	0.02	3.78	0.59	119	18	0.9	0.1	<0.5	NA	11.3	2.2	15.5	2.6	24.2	2.2	<0.10	NA
13	0.04	0.02	4.05	0.63	111	16	0.9	0.1	<0.5	NA	11.4	2.2	15.9	2.6	28.1	2.5	<0.10	NA
14	0.04	0.02	3.99	0.62	112	17	0.9	0.1	<0.5	NA	9.7	1.9	15.1	2.5	25.1	2.2	<0.10	NA
I.D	**Mo mg/kg**	**+/-**	**Ni mg/kg**	**+/-**	**Pb mg/kg**	**+/-**	**Sb mg/kg**	**+/-**	**Se mg/kg**	**+/-**	**Tl mg/kg**	**+/-**	**U mg/kg**	**+/-**	**V mg/kg**	**+/-**	**Zn mg/kg**	**+/-**
5	<1.2	NA	22.9	2.1	42.6	10.5	0.10	0.02	<0.40	NA	0.37	0.04	1.63	0.16	38.9	4.4	98.0	8.2
5R	<1.2	NA	19.3	1.8	43.5	10.8	0.10	0.02	<0.40	NA	0.32	0.03	1.39	0.14	35.2	4.0	92.6	7.8
6	<1.2	NA	19.0	1.7	43.3	10.7	0.11	0.02	<0.40	NA	0.31	0.03	1.41	0.14	33.4	3.8	91.0	7.6
7	<1.2	NA	17.3	1.6	42.8	10.6	0.07	0.01	<0.40	NA	0.30	0.03	1.36	0.14	31.7	3.6	81.8	6.9
7R	<1.2	NA	17.7	1.6	40.2	9.9	0.07	0.01	<0.40	NA	0.31	0.03	1.42	0.14	32.1	3.7	82.8	6.9
8	<1.2	NA	20.0	1.8	50.0	12.4	0.08	0.01	<0.40	NA	0.34	0.04	1.58	0.16	35.8	4.1	101	9
9	<1.2	NA	21.1	1.9	42.7	10.6	0.08	0.01	<0.40	NA	0.38	0.04	1.58	0.16	36.7	4.2	102	9
10	<1.2	NA	20.7	1.9	40.8	10.1	0.07	0.01	<0.40	NA	0.35	0.04	1.56	0.16	35.7	4.1	104	9
11	<1.2	NA	20.0	1.8	34.9	8.6	0.07	0.01	<0.40	NA	0.34	0.04	1.5	0.15	35.6	4.1	104	9
12	<1.2	NA	17.7	1.6	39.2	9.7	0.08	0.01	<0.40	NA	0.33	0.03	1.45	0.15	33.2	3.8	85.7	7.2
13	<1.2	NA	18.1	1.6	40.7	10.1	0.08	0.01	<0.40	NA	0.32	0.03	1.48	0.15	35.0	4.0	100	8
14	<1.2	NA	17.5	1.6	41.6	10.3	0.08	0.01	<0.40	NA	0.31	0.03	1.47	0.15	32.9	3.8	85.9	7.2

Table 11: Sample results for Ag, As, Ba, Be, Cd, Co, Cr, Cu, Hg, Mo, Ni, Pb, Sb, Se, Tl, U, V and Zn from the systematic grid samples. The results for sample 6 are the mean concentration values from the ten sub-samples analyzed, after the removal of outliers.

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GLOSSARY

ANOVA: a statistical tool used to determine if it is probable, above a pre-defined confidence level, that one or more groups of data is/are different from the other groups (Minitab, 2017)

Anthropogenic: "originating in human activity" (Canadian English Oxford Dictionary [CEOD], 2018a)

Bioavailability: the degree and rate at which a substance (such as a drug) is absorbed into a living system or is made available at the site of physiological activity (Merriam Webster Dictionary, 2018a)

Biomagnification: the process by which a compound (such as a pollutant or pesticide) increases its concentration in the tissues of organisms as it travels up the food chain (Merriam Webster Dictionary, 2018b)

Fundamental Error: an inherent property of the sample, determined by chemical or physical differences in the particles of the sample

Geochemical Background: the natural abundance of an element in barren earth material (Hawkes & Webb, 1962)

Grouping and Segregation Error: the errors from sampling arising from the distributional heterogeneity of the sample

Grubbs' Test: "used to detect a single outlier in a univariate data set that follows an approximately normal distribution" (National Institute of Standards and Technology, 2012)

Guidance Manual for Environmental Site Characterization in Support of Environmental and Human Health Risk Assessment (MESC)(12)

Guidance for Obtaining Representative Subsamples from Particulate Laboratory Samples (GORS)(14)

Increment Delimitation Error: the errors from identifying the correct sub-sample to take

Increment Extraction Error: the errors associated with removing the intended sample or sub-sample, such as considering the shape of the sampling device cutting edges

Mobility: elements and compounds may move through the soil and into other environmental compartments, "if there is [a] change in soil cation, pH or oxidation–reduction potential" (Ogundiran & Osibanjo 2009). The amount of organic matter and the texture of the soil also affects contaminant mobility. Finer texture soils have a greater surface area, immobilizing a greater fraction of a contaminant (MOECC, 2011a)Non-threshold Contaminant: has no measurable exposure at which it does not produce an adverse effect in an organism

Preparation Error: errors from sample degradation, gross errors and analyte loss or gain during sampling, transportation, preparation and/or analysis

Protocol for Analytical Methods Used in the Assessment of Properties under Part XV.1 of the Environmental Protection Act (PAMEPA)(12)

Reconnaissance: "preliminary surveying or research" (CEOD, 2018b)

Tessier Fractionation: "an analytical procedure involving sequential chemical extractions … for the partitioning of particulate trace metals into five fractions: exchangeable, bound to carbonates, bound to Fe-Mn oxides, bound to organic matter, and residual" (Tessier et al., 1979)

Threshold Contaminant: has a measurable exposure that is required to produce an adverse effect in an organism and requires the use of the threshold model of assessing risk

ACRONYMS

ANOVA:	Analysis of Variance
ATSDR:	Agency for Toxic Substances and Disease Registry
CCME:	Canadian Council of the Ministers of the Environment
CRM:	Certified Reference Material
DC:	Direct Contact
EB:	Equipment Bank
FB:	Field Blank
FBS1:	Fisherbrand™ Sparkleen™ 1
G:	Ingestion
GEA2:	Guide for completing phase two environmental site assessments under Ontario Regulation 153/04
GORS:	Guidance for Obtaining Representative Subsamples from Particulate Laboratory Samples
I:	Inhalation
IARC:	International Agency for Research on Cancer
ICP-AES:	Inductively Coupled Atomic Emission Spectrometer
ICP-MS:	Inductively Coupled Mass Spectrometer
LCS:	laboratory Control Sample
MB:	Method Preparation Blank

MESC: Guidance Manual for Environmental Site Characterization in Support of Environmental and Human Health Risk Assessment

MOECC: Ministry of Environment and Climate Change

MXS: Matrix Spike

NIST: National Institute of Standards and Technology

OTR: Ontario Typical Range

OTR98: Ontario Typical Range 98

PAMEPA: Protocol for Analytical Methods Used in the Assessment of Properties Under Part XV.1 of the EPA

RDSWS: Rationale for the Development of Soil and Ground Water Standards for use a Contaminated Sites in Ontario

RPD: Replicate Difference

SMPD: Sample Duplicate

SSEPA: Soil, Ground Water and Sediment Standards for Use Under Part XV.I of the Environmental Protection Act

TB: Trip Blank

USEPA: United States Environmental Protection Agency

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