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# Spatial distribution of lead in soil and sediment in Iqaluit, Northwest Territories and links with human health

Liisa Ann Peramaki
*Wilfrid Laurier University*

# SPATIAL DISTRIBUTION OF LEAD IN SOIL AND SEDIMENT IN IQALUIT, NORTHWEST TERRITORIES AND LINKS WITH HUMAN HEALTH

By

Liisa Peramaki

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**ABSTRACT**

The Baffin Regional Health Board has recently expressed concern over lead poisoning in Iqaluit, NWT, manifested by low haemoglobin levels in children. Several studies in temperate regions have demonstrated links between environmental lead and human health. However, little is know about these links in a permafrost environment. While humans are exposed to lead via a number of different pathways, soils and sediments are two major pathways. The purpose of this study is to determine the spatial distribution of soil and sediment-associated lead in Iqaluit and to assess probable pathways between high lead levels and children. The research hypothesis is that elevated levels of lead (ie. above natural background levels) are present in the study area. Three major objectives were identified: 1) to examine the distribution of total and bioavailable lead in soil and sediment; 2) to determine the proportion of total lead which is bioavailable; and 3) to infer possible linkages with human health.

Field work was conducted in the summer of 1996 to collect soil and sediment samples from the study area. Samples were collected from areas outside the built-up area of the town, to reflect natural background concentrations. Samples were also collected from known point sources of lead: the Upper Base, the Sylvia Grinnell Dump (West 40) and the Metal Dump (North 40). Systematic sampling of the built-up areas of Iqaluit and Apex, a satellite community, was conducted using grids 200 by 200 m. Areas where humans may contact contaminated soil were targeted for sampling, and included playgrounds, roads, culverts and beaches. In the laboratory, samples were dried and sieved to less than 63 μm, because of the relationship between decreasing grain size and increasing lead concentrations, the role of fine-grained particles in fluvial transport and the ability of small particles to adhere to human hands and be ingested. Samples were analyzed for total and bioavailable (operationally-defined as 0.5N HCl extractable) lead concentrations.

The research findings reveal that elevated levels of bioavailable lead (ie. above average background concentrations of 10 ppm) are present in the study area. Total lead concentrations generally do not exceed environmental guidelines. However, lead concentrations in the Sylvia Grinnell Dump and Apex and Lower Base area of town exceed OMEE recommended guidelines derived from health-based criteria. The research concludes that there is not a serious health hazard posed by lead levels in the soil and sediment in the study area. However, several environmental (elevated lead levels, bioavailable forms of lead, bare soil surfaces) and behavioural factors (vigorous play outside) create a risk of lead exposure.

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# CHAPTER 1: INTRODUCTION

## 1.1 PROBLEM STATEMENT

Lead poses a health hazard to humans. High levels of lead in the body can cause a number of health problems, including brain disease, kidney damage, and anaemia. While high lead levels may affect people of all ages, children are most vulnerable to its toxic effects.

Recently, the Baffin Regional Health Board (BRHB) has expressed concern over possible lead poisoning, manifested by low haemoglobin levels among children, in the town of Iqaluit, NWT (Pat Kermeen, personal communication). Several studies in temperate regions have demonstrated links between high lead levels in humans and lead in the environment (eg. Watt et al., 1993; Cotter-Howells and Thornton, 1991; Hertzman et al., 1991; Stark et al., 1982). This study investigates the BRHB's concern of a possible link between human health and environmental lead. The purpose of the research is to determine the spatial distribution of soil and sediment-associated lead in the area, and to assess probable pathways between any high levels in the environment and children in Iqaluit.

Located on southern Baffin Island, Iqaluit is an area of continuous permafrost (Figure 1.1). Little is known about the distribution of lead in northern Canadian communities. Furthermore, links between high levels of lead in the environment and in humans are convoluted and often unclear. Less is known about these links in a permafrost environment. A combination of environmental and human factors in Iqaluit create a unique environment in which to study lead in soil and sediment and links with health.

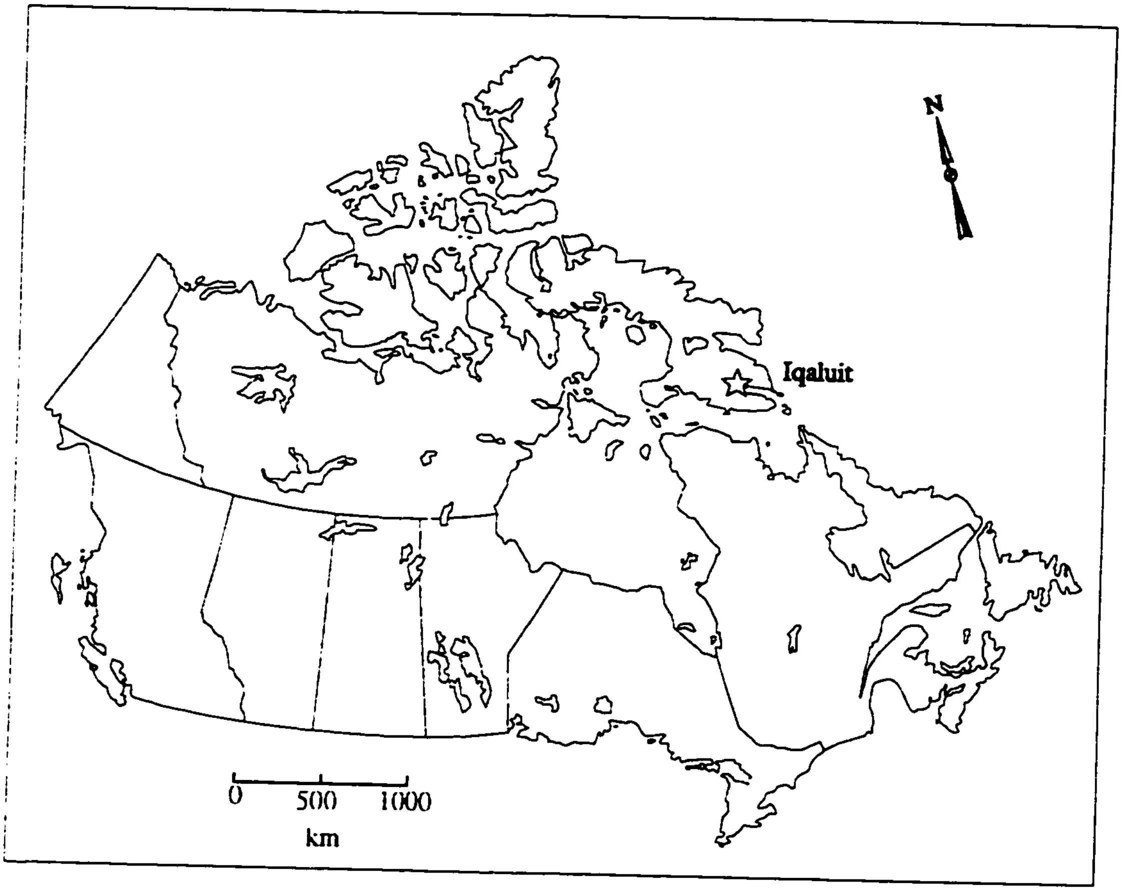


**Figure 1.1 Location of Study Area**

First, Arctic environments are particularly vulnerable to the effects of contaminants. Cold temperatures and reduced ultraviolet radiation slow the degradation of contaminants. Permafrost affects the rate of chemical reactions and biological activities within the soil because of its low temperature, and also generally produces impermeable conditions with respect to potential leaching and migration of substances through frozen layers (Linell and Tedrow, 1981). Consequently, contaminants, such as lead, are less mobile and take much longer to break down in Arctic environments than in temperate regions.

Second, historically, Iqaluit has had strong ties to the military, whose presence has created several potential local sources of lead. The town of Frobisher Bay grew out of an American Air Force base, built during the Second World War to ferry aircraft to the United Kingdom (Hamilton, 1993). During the 1950s, the United States built a radar station and expanded the air services (BRHB, 1994). During the Cold War, the Distant Early Warning (DEW) Line was established and Frobisher Bay became a major trans-shipment, as well as communications and construction centre for the Eastern Arctic (BRHB, 1994).

Third, Iqaluit is experiencing very rapid growth and has a young population. Iqaluit, the largest town in the Eastern Arctic, remains the administrative centre and will be the capital of Nunavut in 1999. In 1991, the population was slightly more than 3500 (BRHB, 1994), and in 1996, the population was 4220 (Soubliere, 1997). Iqaluit is expected to continue to grow and estimates predict a population of close to 5000 by the year 2006 (BRHB, 1994). Currently, over 30 % of the total population is under 15 years of age (Table 1.1).

Table 1.1 Population of Iqaluit, by Age Group, 1991 (BRHB, 1994)

| Age | Number | Percentage of Total Population |
|---|---|---|
| 0 - 14 | 1166 | 32.8 |
| 15 - 24 | 624 | 17.6 |
| 25 - 44 | 1333 | 37.5 |
| 45 - 64 | 384 | 10.8 |
| 65 + | 45 | 1.3 |

Given that children are most vulnerable to the toxic effects of lead, the potential for lead-related health problems in the study area is high.

## 1.2 HUMAN EXPOSURE TO LEAD

Lead is ubiquitous in the environment. It is a major constituent in more than 200 minerals; the most abundant of which is galena (PbS). Lead is a trace constituent in rocks, soil, sediment, water, air, and plant and animal life. The lead cycle involves the movement of lead between certain reservoirs: the atmosphere, lithosphere, hydrosphere, and biosphere. Although the atmospheric reservoir is small, it is significant in the transfer of lead between the various reservoirs (Nriagu, 1978a). For example, particulate forms of lead are removed from the atmosphere by sedimentation, rainfall and snowfall. Lead is one part of the biogeochemical cycle (Figure 1.2), and is transported by air, water, and gravity, until it reaches a geochemical sink (Davies, 1980). Sinks are natural reservoirs which absorb or remove a substance from a system. Soils and sediments are the ultimate sinks for lead (Haar, 1975).

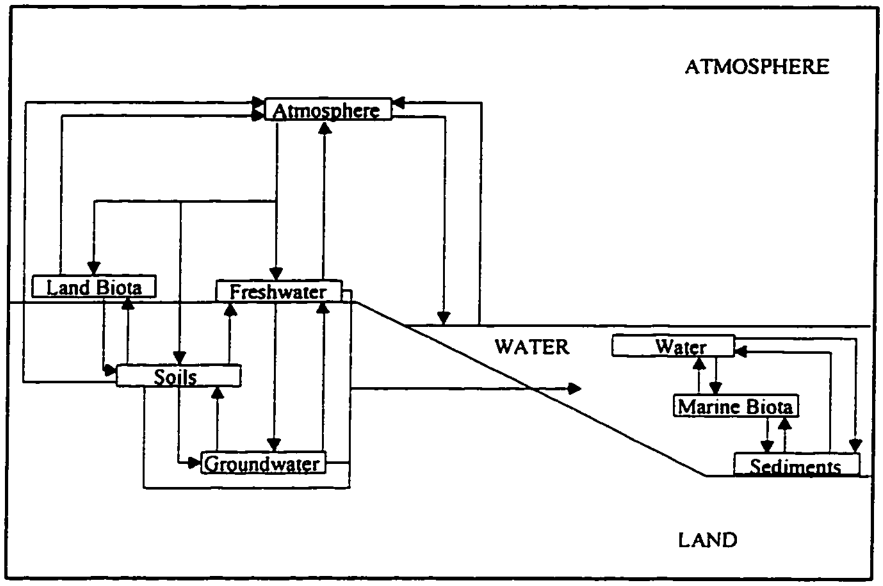


Figure 1.2 Lead Cycle (Revised from: Nriagu, 1978a)

While lead occurs naturally, concentrations in terrestrial and aquatic environments have increased due to human activities, such as mining, production, use, and deposition of lead-containing materials (Brinkmann, 1994). Prior to 1975, the burning of leaded gasoline was the most general source of environmental lead contamination (Working Group on Lead, 1974). Today, the use of lead has greatly decreased, primarily due to the regulation of lead in gasoline in 1976 and prohibition in 1990, and due to the removal of lead from paint in 1975 (OMEE, 1993; Madhavan et al., 1989). However, elevated lead levels are still present in the environment due to its widespread use in the past, as well as its persistence and permanence in the environment (OMEE, 1993; Nriagu, 1978b). The concentration at which lead levels are considered "elevated," in both humans and the environment, is a matter of much debate, and will be discussed in Chapter 2: Literature Review.

Given the toxicity of lead, there is concern over the health effects of human exposure, particularly in children, to the present levels of lead in the environment. There are several direct and indirect pathways of human exposure to lead (Figure 1.3). The focus of this thesis is the exposure pathways of lead in soil and sediment to humans.

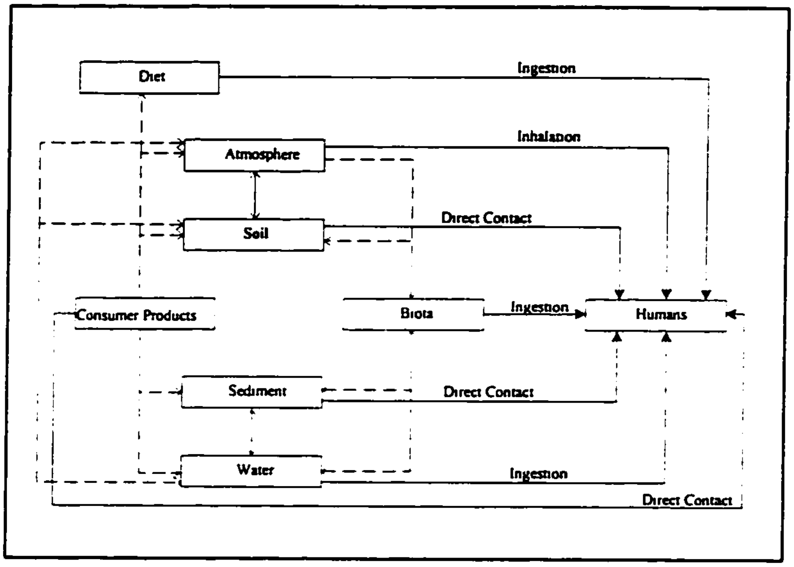


Figure 1.3 Pathways of Human Exposure to Lead (solid lines indicate a direct route between lead source and humans; dashed lines indicate pathways between lead sources) (Revised from: WHO, 1983)

Previously, food was the greatest source of direct exposure because of lead-based solder used in food cans (OMEE, 1993). However, reduction in this use of lead solder has made diet a minor contributor to total lead exposure (Carrington and Bolger, 1992). Like food, the relative contribution of airborne lead to overall exposure has decreased significantly over the last decade (OMEE, 1993). This decrease is primarily the result of the elimination of lead from gasoline and automobile emissions.

Soil is a major pathway of human exposure to lead. Soil is defined as a "complex mixture of inorganic minerals (mostly clay, silt, and sand), decaying organic matter, water, air, and living organisms" (Miller, 1990: A51). Soils are derived from weathering of rocks, and may either remain in place or be transported as fine particles by various means, such as glacial action, wind, and water (Yong et al., 1992). Soil is an important sink for lead, and while lead accumulates rapidly, it is depleted slowly by leaching, plant uptake, erosion or deflation (Davies, 1980). Lead persists in soil and, therefore, this pathway has increased in significance, making it a major route of exposure. The Royal Commission on Environmental Pollution concluded that lead in soil, which is carried to the mouth, may constitute over half of young children's total lead uptake (Davies and Wixson, 1986). Human exposure occurs primarily through inhalation or ingestion. Soil ingestion is multifaceted and includes pica (eating of non-food items), geophagy (the practice of earth eating to alleviate nutrient deficiencies) and inadvertent ingestion (Sheppard et al., 1995).

Sediment is another pathway of human exposure. Sediment is defined as "particles derived from rocks or biological materials that have been transported by fluid, or solid material suspended in or settled from water" (Horowitz, 1985: 3). Human exposure to lead from sediment may be less direct than exposure from soil. However, marine biota may ingest lead-containing sediment, thereby initiating the transfer through the food chain, ultimately reaching humans (Connor et al., 1994; Campbell, et al., 1988). Lead in sediment can also be mobilized into water and consumed by humans. Finally, sediment can be directly exposed to humans when stream beds are uncovered during periods of low or no flow, or after periods of high flow which transport sediment to the flood plains.

## 1.3 RESEARCH HYPOTHESIS AND OBJECTIVES

The purpose of this research is to determine the distribution of soil and sediment-associated lead in Iqaluit, and to assess probable pathways between any high levels in the environment and children. The research hypothesis is that elevated levels of lead (ie. above natural background concentrations) are present in the soil and sediment in the study area. To test this hypothesis and fulfil the purpose of the research, three major objectives were identified:

1) to examine the distribution of total and bioavailable lead in soil and sediment;

2) to determine the proportion of total lead which is bioavailable;

3) to infer possible linkages with human health.

## 1.4 OUTLINE OF THESIS

Chapter 2 provides a review of literature on lead contamination in soil and sediment. Chapter 3 describes the study area in greater detail and outlines methods used in the field and laboratory components of the research. Chapter 4 presents the results of the laboratory analysis, combined with discussion of the findings. Chapter 5 concludes the thesis by discussing the links between lead in soil and sediment and human health in Iqaluit. Finally, recommendations for management and future research are provided.

# CHAPTER 2: LITERATURE REVIEW

## 2.1 INTRODUCTION

This chapter reviews background literature on lead contamination in soil and sediment, and its relationship to human health. Sections 2.2 and 2.3 focus on lead in soil and sediment. Natural and elevated lead levels, as well as sampling strategies, are reviewed. Section 2.4 presents the factors which influence the concentration and mobility of lead in soil and sediment. Section 2.5 outlines contaminant research undertaken in the Arctic, with particular emphasis on studies in Iqaluit. Section 2.6 defines total and bioavailable lead, and describes the importance of each measurement to human health. The chapter concludes with an overview of literature linking lead in soil with human health, and the physical effects of lead in the human body.

## 2.2 LEAD IN SOIL

Most naturally occurring lead is found in soil, and all soils contains lead derived from parent materials. Natural total lead concentrations in soils vary greatly, but range, on average, between 10 ppm and 37 ppm (Nriagu, 1978b). In tundra soils, the average lead concentration is approximately 13 ppm (Nriagu, 1978b). While it is still possible to measure natural lead concentrations in certain areas, human activities have increasingly contaminated the environment (Ratcliffe, 1981). In fact, few areas on Earth are now free of anthropogenic sources of lead. There is no simple way of recognizing when soil has been contaminated by lead, given that lead occurs naturally (Wixson and Davies, 1993). To identify contamination, it must be determined whether the measured concentration is within the range of what could occur naturally for that soil or whether the measured concentration is anomalous (Wixson and Davies, 1993).

Lead contamination in soils is attributed to various sources, including flaking lead paint, incinerators, vehicular traffic, deposition of air-borne lead and emissions from industries. As lead products break down in the environment, they leave lead-based residues, which often deposit on soil surfaces (Brinkmann, 1994). Lead concentrations in soils in urban areas can be extremely high. For example, lead concentrations of 3357 ppm have been found in a downtown Los Angeles park (Working Group on Lead, 1974). Lead concentrations ranging from 150 to 3000 ppm have been reported for Canadian inner city sites (OMEE, 1994). In urban soils, lead is found to be a mixture of powdered paint and atmospheric fallout of lead particles (Elhelu et al., 1995). High concentrations of soil-lead adjacent to buildings result from leaching of window trim paint or wash-off of roofs or ledges (Elhelu et al., 1995).

Soils in rural areas have also been found to have high lead levels. For example, agricultural areas of Ontario exhibit lead levels ranging from 1.5 to 888 ppm, with a mean of 45.8 ppm (Frank et al., 1976). The sources of lead in rural soils include pesticides and fertilizers, manure and sewage sludge, and atmospheric fallout from urban, transportation and industrial activities (Jones, 1991; Frank et al., 1976).

Monitoring lead concentrations in soils is important for a variety of reasons. Lead concentrations in soil often reflect contamination by anthropogenic activities. In addition, there is a relationship between soil contamination and ecosystem health. Lead in soil can be taken up by plants, animals and humans, thereby impacting organism health. Consequently, most governmental agencies have adopted guidelines to regulate lead concentrations in soil. The Northwest Territories, for example, has adopted the Canadian Council of Ministers of the Environment soil-lead guidelines (CCME, 1991). Site remediation is recommended at total lead concentrations above 375 ppm for agricultural sites, 500 ppm for residential/parkland sites and 1000 ppm for commercial/industrial sites. As part of the NWT, Iqaluit follows these guidelines.

Given the widespread extent of lead contamination in soils, the toxicity of lead and risk of uptake by biota, many researchers have examined the spatial distribution of lead in soil. These studies have employed various sampling strategies. In a study of urban lead in four Minnesota cities, Mielke et al. (1984/5) examined the general distribution of soil-lead. City maps were marked with transects which passed through rural areas and the central business districts. This sampling procedure was chosen because of its simplicity and because clusters of urban lead concentrations are often easily detected (Mielke et al., 1984/5). Thornton and Webb (1980) used a grid system to collect soil samples for the purpose of documenting the distribution of lead in soil (in Brinkmann, 1994). Using this systematic sampling procedure, patterns emerged which reflected natural geological phenomena as well as human land uses (Brinkmann, 1994).

In a study of lead levels in Mount Pleasant, Michigan, Francek (1992) examined lead in soil from different land uses. A stratified sampling strategy was employed. Strata chosen included: natural background, around the city limits using a grid system; street intersections; homes in varying age classes; schools, at building entrances and playgrounds and; a miscellaneous group, including a city dump and a scrap yard. Using stratified sampling, Francek was able to differentiate lead concentrations from separate land use groups. Several studies have examined soil-lead levels at particular sites and sources of lead, such as battery plants (Moseholm et al., 1992; Angle et al., 1975) and lead smelters (Hilts, 1996; Cotter-Howells and Thornton, 1991; Hertzman et al., 1991). Elevated levels of lead are reported in these studies, which utilize site-specific sampling.

In studies particularly concerned with threat to human health, areas where humans may be in contact with lead contaminated soil are targeted for sampling. For example, Schmitt et al. (1979) sampled boulevards, roadside gutters and vacant lots adjacent to main streets in downtown, residential and commercial districts, where children could readily come in contact with soil. Similarly, Rabinowitz and Bellinger (1988) gave preference to any obvious play areas in their investigation of the connection between soil and blood-lead levels among a group of Boston children. The authors found targeting areas of human activity was an effective sampling strategy for studies investigating links between lead in soil and human health.

In most studies, samples are taken at the soil surface, or at the uppermost few centimetres of the surface (eg. Brinkmann, 1994; Mielke, 1993; Watt et al., 1993; Cotter-Howells and Thornton, 1991; Mielke et al., 1984). Human exposure to lead in soil is also more common at the surface than at depth (Brinkmann, 1994; Chaney et al., 1989). Studies which have collected soil samples from depth have found decreasing lead concentrations with increasing depth (Stoker and Seager, 1976; Fairey and Gray, 1970). Puchelt et al. (1993) found that lead contamination of soil reached depths of only 10 to 15 cm, on average.

## 2.3 LEAD IN SEDIMENT

Like soils in the terrestrial environment, sediments represent the primary sink for lead in the aquatic environment (Nriagu, 1978b). After entering aquatic environments, lead is distributed among sediment, water, and biotic compartments. Materials containing lead settle out of the water column (Campbell et al., 1988). Processes of deposition, such as flocculation (a process that causes fine muds and clays to agglomerate and sink rather than remain in suspension) and precipitation, may also remove lead from the water column (Campbell et al., 1988). Because of these processes, the lead concentration in suspended sediment and the top few centimetres of bottom sediment is generally much higher than dissolved lead concentrations in the water column (Combest, 1991; Horowitz, 1985). For example, lead concentrations from the Elbe River in Germany are 500 mg/kg in bottom sediment and only 0.005 mg/kg in water (Horowitz, 1985). This is due to the fact that lead is rapidly removed from water due to preferential binding to sediment (Haar, 1975).

The natural background concentration of lead in sediment is affected by the composition of soils and bedrock geology of the drainage basin (Mudroch and Duncan, 1986). Through natural and anthropogenic processes, lead often accumulates to high levels in sediments. Human activities have increased the amount of trace metals entering the aquatic environment from terrestrial sources through a variety of pathways, including the atmosphere and soil (Tessier et al., 1980). For example, aquatic environments can become contaminated with lead from point sources, such as sewage treatment plants, atmospheric fallout, ground water leachate, and stormwater runoff. Urban runoff from city streets, in particular, introduces lead to aquatic environments at concentrations that often exceed water quality criteria (Stone and Marsalek, 1996; Combest, 1991).

Investigating trace metal concentrations in sediments is important for a number of reasons. First, trace metals, such as lead, in the sediments can be released into the water column by changes in environmental conditions, such as pH, and salinity (Horowitz, 1985; Mudroch et al., 1988; Vaithiyanathan et al., 1993). Sediment-bound lead released into the water column can enter the food chain or be directly consumed by humans (Horowitz, 1985). Secondly, sediments are biologically important habitats (Campbell et al., 1988). A wide variety of organisms, including benthic invertebrates, are directly exposed to sediment-bound metals through surface contact and accidental or intentional ingestion during feeding (Horowitz, 1988; Luoma, 1988). Not only is this harmful to organisms, but it may also increase the flux of metals into aquatic food chains (Oliver, 1973). Thirdly, sediments act as carriers of trace metals (Vaithiyanathan et al., 1993), and therefore river transport of trace metals is dominated by sediment transport processes (Horowitz, 1985). Consequently, the spatial pattern and distribution of metal contamination in the aquatic environment is governed by sediment transport processes (Hakanson, 1984). A large proportion of suspended solids transported in fluvial systems is less than 63 μm (Stone and Droppo, 1994; Forstner and Wittmann, 1979).

Investigating lead concentrations in sediments allows the degree and spatial extent of sediment contamination and toxicity to aquatic biota to be assessed (Mudroch et al., 1988). Guidelines have been established to regulate lead concentrations in sediment and to protect environmental health. The Ontario Ministry of Environment, for example, has established aquatic sediment quality guidelines. The lowest effect level for total lead in sediment is 31 ppm and the severe effect level is 250 ppm (in Stone and Marsalek, 1996).

Several studies have investigated the distribution and concentration of lead in sediment. Nriagu (1978b) compiled a list of lead concentrations in river and stream sediments from various parts of the world. An average lead concentration in riverine sediments, with evidence of pollution, was estimated at 98 ppm. This value represents an increase of 30 % above natural concentrations (Nriagu, 1978b). The background concentration of lead in sediment varies over a narrow range (Mudroch and Duncan, 1986; Nriagu, 1978b). The average concentration of lead in sediments from 53 Arctic coastal streams was 3.9 ppm (Nriagu, 1978b), which is much lower than the concentrations in polluted sediments.

Mudroch et al. (1988) compiled metal-sediment data for Great Lakes sediments (Table 2.1). Their data show the range of lead concentrations in sediment and increase above background levels. Lead concentrations in harbours, for example, are much higher than background because of human activities, such as marine vessel traffic and urban discharge.

Table 2.1 Total Lead Concentration in Sediment (ppm), Great Lakes (Mudroch et al., 1988)

| Collection Area | Surface | Background |
|---|---|---|
| Depositional basins | 3.0-299 | 8-68 |
| Areas with no fine grained-sediments | 1.8-287 | 18-25 |
| Embayments | 0.3-520 | 8-93 |
| Harbours | 1.0-1600 | 28 (mean) |
| River mouths | 1.2-258 | not available |

## 2.4 FACTORS INFLUENCING LEAD IN SOIL AND SEDIMENT

Several factors, such as grain size, surface area, surface charge, composition and cation exchange capacity, influence lead in soil and sediment. These factors, as well as the mobility of lead, are discussed in the following review of literature.

### 2.4.1 Trace Metal Concentrations

Many factors affect the capacity of soil or sediment particles to concentrate and retain trace metals, such as lead. Horowitz and Elrick (1987) have divided the most important factors into two general categories: physical (grain size, surface area, surface charge) and chemical (composition, cation exchange capacity).

Grain size is the most commonly cited and analyzed factor influencing trace metal concentrations (Horowitz and Elrick, 1987). There is a strong positive correlation between decreasing grain size and increasing trace metal concentrations (Horowitz, 1985). This relationship has been reported by several authors (eg. Stone and Marsalek, 1996; Vaithiyanathan et al., 1993; Mantei and Foster, 1991; Martincic et al., 1990; Poulton et al., 1988; Oliver, 1973). The correlation between grain size and trace metal concentrations is mainly due to the influence of particle surface area (Combest, 1991). Fine-grained particles, such as clays, have large surface areas for metal binding. While trace metals can accumulate on larger particle sizes, such as sands and gravels, high concentrations are more commonly associated with fine-grained material (Horowitz, 1985). Horowitz and Elrick (1987) concluded that the most important ranges of grain size in the examination of trace metals are the <63 μm or <125 μm fractions. Surface charge is another factor influencing trace metal concentrations on soil and sediment particles. As surface charge increases, trace metal concentration also increases.

The second most commonly cited and analyzed factor influencing trace metal concentrations is the composition and/or concentration of geochemical phases. Investigations of particle composition are based on chemical extractions, which are used to operationally-define metal association with particular geochemical phases. Particles which preferentially bind metals tend to be thermodynamically unstable and are amorphous or cryptocrystalline (Horowitz, 1985). The most common materials meeting these criteria are clay minerals, organic matter, hydrous manganese, and hydrous iron oxides. As a result, the most important surfaces for concentrating trace metals are iron and manganese oxides and hydroxides, organic matter and clay minerals (Horowitz and Elrick, 1987).

Cation exchange capacity influences the concentration of trace metals on soil or sediment particles, and refers to the ability of a particle to hold, or sorb, cations (Rutherford, 1977). Trace metals are cations (ie. have a positive ionic charge), while surfaces of most materials have a net negative charge. As cation exchange capacity increases, trace metal concentrations also increase. As grain size decreases and surface area increases, cation exchange capacity increases significantly (Horowitz, 1985).

In summary, physical and chemical factors affect the capacity of soil and sediment particles to collect and concentrate trace metals. Increases in metal concentrations are strongly correlated with decreasing grain size and increasing surface area, surface charge, cation exchange capacity, and increasing concentrations of iron and manganese oxides, organic matter, and clay minerals. Horowitz (1985) states that it is not always possible to distinguish between effects caused by surface area, cation exchange capacity, surface charge, and effects due to grain size. Therefore, if only one of the above factors is to be determined during chemical data analysis, grain size is the preferred parameter, because it combines many of the other factors (Horowitz, 1985).

### 2.4.2 Mobility

For the purpose of this discussion, mobility refers to the transport of lead, in terrestrial and aquatic environments, by physical and chemical processes. Movement of lead over long distances generally involves physical transport in particulate form (Brinkmann, 1994; Nriagu, 1978b). Lead is transported on the Earth's surface predominantly by aeolian and fluvial processes. However, lead in soil may also be transported by humans. For example, soil on shoes can be tracked into homes and become part of housedust (Chaney et al., 1989).

Lead may also be chemically transported and its mobility depends on several factors, including: surface characteristics, texture, and clay type and concentration; the kind and strength of the bond; and environmental conditions such as pH, salinity, drainage, and physical disturbance (Horowitz, 1985; Calmano and Forstner, 1983; Golterman et al., 1983; Zimdahl and Skogerboe, 1977).

Sediment-associated lead is commonly regarded to be geochemically immobile. The low concentration of lead in surface waters is evidence that lead is not readily solubilized (Nriagu, 1978b). However, if the environmental conditions change, for example by a decrease in pH or increase in salinity of overlying water, sediment-associated lead will desorb into the water column (Golterman et al., 1983; Horowitz, 1985). Lead becomes more soluble at a pH below 6.5 (Scheuhammer and Norris, 1995).

The mobility of lead in soils is extremely low (Turjoman and Fuller, 1986), and it is generally accepted that once lead is deposited in the soil, it remains relatively stable (Brinkmann, 1994). Lead migrates only very slowly through soil profiles (Chamberlain, 1983) and, as a result, soil-lead concentrations are higher at the surface than at depth (Madhavan et al., 1989). Conditions causing increased lead mobility include low soil or surface water pH, high amounts of annual precipitation and absence of organic compounds in soil (Scheuhammer and Norris, 1995). Movement of lead in soil profiles depends largely on the dissolution of lead particles in groundwater (Zimdahl and Skogerboe, 1977). If the dissolved lead remains in a soluble form, then it may be leached through the soil profile. However, the dissolved lead can also be immobilized by soil microorganisms, precipitation, sorption onto soil entities, or fixation by materials (Zimdahl and Skogerboe, 1977).

The low mobility of lead means that it stays near the soil surface where it can easily come into contact with humans (Madhavan et al., 1989). Over time, as more lead residue is added to the soil, lead concentrations can reach levels harmful to humans upon repeated exposure (Brinkmann, 1994). The limited mobility of lead in soil is further enhanced in Arctic areas, where permafrost generally creates impermeable conditions.

## 2.5 CONTAMINANT RESEARCH IN THE ARCTIC

Current research has suggested that the Arctic is receiving contaminants from localized sources, such as DEW Line stations and waste disposal sites, as well as from distance sources. In remote Arctic areas, the atmosphere is the predominant source of anthropogenic metals. As a result, a great deal of contaminant research has focused on atmospheric pathways from industrial areas to the Arctic (eg. Ayotte et al., 1995; Ford et al., 1995; Landers et al., 1995; Pacyna, 1995; Barrie et al., 1992; Hermanson, 1991; Barrie and Hoff, 1985). Using sediment cores from an Arctic lake undisturbed by human activity, Hermanson (1991) found that heavy metals, including lead, deposited from the atmosphere have doubled since the Second World War. The presence of elevated lead was attributed to sources outside of the North American Arctic.

A substantial amount of research has been undertaken on contaminants in Arctic food chains and resulting human health risks (eg. Kinloch et al., 1992; Muir et al., 1992; Kuhnlein, 1989; Eaton, 1982). Environmental testing in Iqaluit has focused on contamination of shellfish in the harbour. From 1983 to 1985, clams sampled from Koojesse Inlet showed elevated levels of faecal coliform and some metals, particularly cadmium (Environmental Services, 1992). The contamination was attributed to the sewage system. A spill from the sewage lagoon a few years later renewed concern, and in 1991, the Department of Fisheries and Oceans reported that clams were not fit for human consumption (BRHB, 1994). Clams remain unfit for consumption and traces of contamination from the sewage lagoon were found in clams at Tarr Inlet, south of Apex, over 5 km away (BRHB, 1994).

Despite the growing research attention focused on contaminants in the Arctic, little research has been conducted on lead in soil. Most studies of lead contamination in the Baffin Region have focused primarily on specific locations, particularly waste disposal sites and their runoff. Haertling (1988) sampled the former military waste disposal site in Sylvia Grinnell Park in Iqaluit. Water, soil and sediment samples were tested for PCB and trace metal (As, Cr, Sb, V, Zn) concentrations. Haertling found high trace metal concentrations in soil directly downslope of the dump, which decreased rapidly with distance from the site. A single plume of contaminants from the middle of the dump was stopped by bedrock outcrops. Trace metal concentrations in sediment were low.

In 1994, the Environmental Sciences Group (ESG) conducted site-specific sampling in Iqaluit, as part of a larger project (Dew Line Cleanup Project). The purpose of the research was to determine the extent of contamination in soil, sediment, plants and water. Sites with excessive concentrations, as defined by the ESG's DEW Line Cleanup Criteria, would be targeted for remediation (ESG, 1995). The ESG sampled the Metal Dump (North 40), the Sylvia Grinnell Dump (West 40), and the Upper Base (former US military communications site). Table 2.2 summarizes the total soil-lead concentrations from the sample sites.

Background concentrations of soil-lead, based on only eight samples, were found to be below the detection limit and estimated at 5 ppm. Comparing concentrations at the sample sites to background concentrations, elevated lead levels were evident. The results of the research prompted the complete cleanup of the Upper Base site, including removal of building materials and contaminated soil. At North 40, the maximum soil-lead levels exceeded ESG criteria and the ESG recommended discontinuing use of the North 40 for waste disposal following cleanup of the dump. Nevertheless, dumping continues at the North 40 dump. The ESG also concluded that lead in soil is elevated at the Sylvia Grinnell

Dump (West 40) and recommended removing metal debris from the cliff. Today, the debris still remains.

Table 2.2 Total Lead Concentration in Soil (ppm), Iqaluit (ESG, 1995)

| Description | Number of Samples | Minimum | Maximum | Mean | Standard Deviation |
|---|---|---|---|---|---|
| Upper Base: Building | 36 | <10 | 9680 | 300 | 1640 |
| Upper Base: Building | 6 | <10 | 188 | 36 | 75 |
| Upper Base: Outfall | 5 | <10 | 12.1 | 7.3 | 3.3 |
| Upper Base: Landfill | 8 | <10 | 108 | 53 | 44 |
| Upper Base: Main Site | 24 | <10 | 2760 | 173 | 560 |
| Metal Dump (North 40) | 23 | <10 | 249 | 42 | 57 |
| Sylvia Grinnell Dump (West 40) | 7 | <10 | 1140 | 293 | 416 |

The Department of Indian Affairs and Northern Development monitors water flowing from North 40 (Paul Smith, personal communication). Water analyses in June 1990 revealed lead concentrations between 24 and 29 μg/L at pH 7.0. The ESG (1995) analyzed two water samples from the drainage originating in North 40 and found lead was below detection limits.

## 2.6 TOTAL AND BIOAVAILABLE LEAD

Most studies of lead in soil and sediment determine total lead concentration, which refers to the concentration of lead after complete dissolution or decomposition of the sample. This can be determined accurately and precisely using many different analytical procedures

(Horowitz, 1988). In general, an acid extraction to solubilize the lead is followed by analysis using atomic absorption spectrometry (Harrison and Laxen, 1977).

In recent years, there has been a shift in focus from total to bioavailable lead concentrations because total concentrations of lead cannot be used to predict environmental impacts (Ankley et al., 1994). Indeed, the health risk posed by lead contaminated soil or sediment is not determined by total lead concentration alone. The bioavailable fraction of total lead is essentially defined as that fraction which can be absorbed into the bloodstream by the organism, including humans (Wixson and Davies, 1993). However, it is rare that all of the ingested or inhaled substance is absorbed. Metals have a direct biological impact only when they are in a biologically available state, able to react with or pass through membranes of living cells (Campbell et al., 1988). Uptake is thus restricted to biologically available metal species (Campbell et al., 1988). The bioavailability of trace metals is commonly correlated with loosely bound, rather than total metal concentrations (Mat et al., 1994). As a result, "a value for total lead in a real environmental sample is almost always an overestimate of the amount of lead that is available and that will be absorbed" (Wixson and Davies, 1993: 9). Hence, the toxicity of lead to an organism depends on the bioavailability of lead and harmful effects occur primarily from the uptake of biologically available lead.

Bioavailability is closely related to solubility and toxicity (Rabinowitz, 1993). A number of environmental and biological factors may affect metal bioavailability and influence the accessibility of metals to organisms, including: the chemical form of lead, pH, texture and organic content (Hilts, 1996; Luoma, 1983). Studies indicate that metal bioavailability tends to be inversely related to the strength of metal-particulate binding in sediments (Luoma, 1983).

Trace metals, such as lead, are usually associated with several geochemical phases. It is generally thought that trace metals in the residual fraction are essentially biologically unavailable (Mat et al., 1994). In contrast, trace metals associated with the non-residual phase (including the extractable phase, carbonate phase, easily reducible phase, moderately reducible phase and organic, sulphides phase) are strongly correlated to the concentration of trace metals in various organisms (Mat et al., 1994). In this thesis, the concentration of non-residual lead is used as an approximation for bioavailable lead.

The term "bioavailability" is operationally-defined, based on the chemical test or toxicity experiment used (Horowitz, 1985). Unfortunately, a universally accepted method of determining bioavailability does not exist, and, unlike total metal concentration, the concept remains subject to interpretation and argument (Horowitz, 1985). Several methods have been used to estimate bioavailability. One common method is *in vitro* or biological experiments using specific organisms, such as soybeans (Pierzynski and Schwab, 1993), bivalves (Bourgoin et al., 1991; Luoma and Bryan, 1982), shorebirds (Connor et al., 1994), rabbits (Davis et al., 1992) and mice (Sheppard et al., 1995; Pascoe et al., 1994). These experiments calculate the concentrations of absorbed metals by feeding organisms soils or sediments with known concentrations of heavy metals, and examining the blood, stomach and intestines.

Other researchers have used chemical extractions to predict metal bioavailability in soils and sediments. These extractions are used to simulate stomach conditions. The dissolution of lead in the stomach, an acidic environment, is necessary for lead absorption in the small intestine (Davis et al., 1993). Davis et al. (1993) state that determination of lead solubility under acidic conditions may provide an estimate of lead bioavailability. Chemical extractions of soil and sediment are often more convenient than biological experiments. Luoma (1983) found that extraction of sediments improved prediction of metal availability. Because of its convenience and effectiveness, several authors have used chemical extractions to estimate operationally-defined bioavailability (eg. Sheppard et al., 1995; Luoma and Bryan, 1981, 1982; Agemian and Chau, 1976).

Rabinowitz (1993), for example, employed acid extraction to assess bioavailability. He hypothesized that "the bioavailable portion of soil-lead can be approximated by the soluble fraction, because lead must first be dissolved to be absorbed. Since we do not have a reliable *in vitro* model of gut transport mechanisms, we rely on selective leaching to characterize the lead and infer its bioavailability" (Rabinowitz, 1993: 441). Stone and Marsalek (1996) also determined metal bioavailability using an acid extraction technique, which was considered to provide a reasonable approximation of the bioavailable metal content in sediment.

After the method of extraction used, bioavailable lead is operationally-defined in this thesis as 0.5N HCl extractable. Hydrochloric acid solution (0.5N) liberates "metals from organic matter, dissolves precipitated salts and extracts adsorbed and all easily extractable metals" (Environment Canada, 1979). This method takes little account of rock types as it dissolves complexed, adsorbed and precipitated metals in sediments with minimum attack on the silicate. According to Agemian and Chau (1976), the 0.5N HCl acid extraction method provides a reasonable estimate of non-residual metal from sediments. Similarly, Bradshaw et al. (1974) found that weak acid extractions, including 0.5N HCl, remove loosely bound and sorbed metal, precipitated salts and possibly attack some of the less resistant silicates.

Several authors have compared acid extraction methods. For example, Agemian and Chau (1977) investigated the commonly used methods of extracting nondetrital metals from sediments. The authors found that the 0.5N HCl acid extraction method was one of the most informative and advantageous methods because it provides high contrast between anomalous and background samples. Agemian and Chau (1977) concluded that the 0.5N HCl extraction is a preferred method. Horowitz (1988) also recommends extraction of sediments with 0.5N HCl to enhance the biological relevance of sediment analysis.

Recent research on human health effects of lead exposure emphasizes the importance of lead bioavailability (eg. Rabinowitz, 1993; Wixson and Davies, 1993; Carlisle and Wade, 1992; Chaney et al., 1989). Because of the strong relationship between bioavailability and toxicity of lead, bioavailable lead concentrations are examined in this thesis. Uptake of lead by organisms, including humans, is restricted to lead which is biologically available. It follows, therefore, that lead in soil or sediment poses a health risk to humans when lead is bioavailable. Harmful health effects may result from humans absorbing excessive amounts of bioavailable lead. Chaney et al. (1989) suggest that the bioavailability of lead in soil must be taken into consideration when setting limits for acceptable levels of lead in soil.

## 2.7 LEAD AND HUMAN HEALTH

Exposure to lead in soils and sediment are two pathways whereby lead may impact human health. While little research has been undertaken to examine the pathway from riverine sediment to humans, a great deal of research has been conducted on the pathway from surface soil to humans. Studies investigating the soil pathway and directly linking soil-lead and blood-lead levels will be reviewed, followed by a discussion of the physical effects of lead inside the human body.

### 2.7.1 Studies Linking Lead in Soil and Lead in Humans

Lead contamination of soil is recognized as a public health hazard. Excessive concentrations of lead in soil have been shown to increase lead levels in humans, particularly children. It has been reported that children with lead poisoning are often found to have ingested soil or dust heavily contaminated with lead (Elhelu et al., 1995)[1]. Exposure to lead via ingestion of soil can occur by inadvertent consumption of soil on the hands or on food items, mouthing of objects, pica, geophagy, or a combination of these pathways (LaGoy, 1987). Small soil particles, particularly those less than 250 μm, are more easily transferred to human hands and may be ingested (Davis et al., 1997, 1992; Ruby et al., 1992; Chaney et al., 1989). Children are particularly at risk from soil-lead exposure. Given the same concentration of lead, children's exposures will be higher than those of adults. This is due to children's high hand-to-mouth behaviour (which can account for 50 % of their total intake), pica, and the amount of time they spend playing outside, coming into contact with,

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[1] While few studies have attempted to correlate soil-lead with house dust lead concentrations, it is generally considered that soil and dust lead are strongly related (Berny et al., 1994; Chaney et al., 1989).

and ingesting or inhaling lead-contaminated soil (Bowers et al., 1994; Watt et al., 1993).

In 1970, Fairey and Gray tested the hypothesis that sufficient quantities of lead were present in soils in Charleston, South Carolina to cause chronic pediatric lead poisoning. Soil samples were taken randomly throughout the city and from yards of houses where pediatric lead poisoning had occurred. Samples taken from homes of poisoned children were significantly more likely to have soil-lead concentrations greater than 500 ppm. Although the source of lead was not determined, the authors concluded that lead concentrations in the soil were sufficient to cause chronic pediatric lead poisoning.

Most human health effects data are based on blood-lead concentration, which is generally accepted as the best indicator of the external dose of lead (Berglund et al., 1994; Stark et al., 1982). Blood-lead concentration is an integrated measure of dose, reflecting total exposure from all sources (Carlisle and Wade, 1992). Several studies have found that lead in soil is positively correlated with blood-lead in humans. The Working Group on Lead found correlations between concentrations of lead in topsoil and blood-lead levels of people living close to three lead processing plants in South Riverdale, Toronto (OMOE, 1975). The study concluded that people living near the three plants had an increased risk of elevated concentrations of lead in their blood. The study also found that exterior sources of lead, such as soil, rather than interior sources, such as paint, water or house dust, were mainly responsible for blood-lead elevations in the three plant areas.

Lead contaminated soil has consistently been found to contribute significantly to children's blood-lead levels. For example, the Working Group on Lead concluded that children who lived in an area where the soil-lead level was greater than 1000 ppm had significantly higher mean blood-lead levels than children who lived in areas where soil-lead was less than 600 ppm (OMOE, 1975).

In an American study, the distribution of lead sources in a residential environment in New Haven, Connecticut was examined (Stark et al., 1982). The study concluded that the most important contributors to variation in children's blood-lead levels were lead in soil and exterior house paint. A study of childhood lead exposure in Trail, B.C. found a significant relationship between soil-lead levels and children's blood-lead levels (Hertzman et al., 1991). Study results concluded that soil-lead levels (mean 1172 ppm) were by far the strongest risk factor associated with elevated blood-lead levels. Similarly, an Australian study found blood-lead levels were significantly raised when soil-lead concentrations ranged from 150 to 500 ppm (Chaney et al., 1989). Studies in temperate climates have also found that there is a seasonal variation in children's blood-lead levels. During the summer months, when children play more regularly outside, their blood-lead levels are elevated (Schell et al., 1997).

Numerous studies have been undertaken to evaluate the potential effects of high soil-lead concentrations on human health. There is some debate regarding the "safe" permissible level of lead in soil, or trigger value. A trigger value is the concentration of lead in soil which indicates the need to evaluate risk to human health from soil-lead (Wixson and Davies, 1993). There is no absolute value of lead in soil that can be used as a trigger. Berny et al. (1994) have suggested that total lead concentrations ranging from 500 to 1000 ppm in soil are responsible for blood-lead concentrations in children above background levels. Other research suggests that an acceptable level of 600 ppm of total lead in soil would contribute no more than 5 µg/dL to total blood-lead of children under 12 years of age, and is therefore “safe” (Madhavan et al., 1989). However, research by Reagan and Silbergeld (1989) in Minnesota suggested that soil-lead levels greater than 50 and up to 150 ppm pose a significant risk to young children and pregnant mothers (in Elhelu et al., 1995). Similarly, Chaney et al. (1989) concluded that soil-lead must be less than 150 ppm in order to prevent excessive lead uptake in children. Madhavan et al. (1989) stated that in an ideal situation, soil would contribute no increment in blood-lead levels. This stringent condition demands an impossible zero level concentration of lead in soil.

Chaney et al. (1989) suggested that any regulation of soil-lead levels must take into consideration the background level of lead consumption and background blood-lead levels for the most exposed, most susceptible children. The Ontario Ministry of Environment and Energy (OMEE) has recommended soil-lead guidelines based on health criteria. The guidelines are derived to "protect the most sensitive receptor exposed to the contaminant" (OMEE, 1993: 29). This sensitive population is identified according to the site’s land use. The guideline for total lead concentration is derived using an equation which considers the following variables: the intake level of concern for the population group most at risk (derived by estimating the lead intake that would result in a blood- lead level of 10 μg/dL); the average body weight of a member of the population at risk; soil consumption rate; and allocation factor (expressed as a percentage of total lead exposure derived from soil).

In commercial and industrial sites, the OMEE considers the receptor at greatest risk to be an adult worker who spends only a portion of the day exposed to the site. Using the health-based criteria, the soil guideline for total lead is calculated at greater than 4100 ppm. However, because of potential off-site impacts of lead levels as high as 4100 ppm, the commercial/industrial decommissioning guideline of 1000 ppm is recommended instead.

The most sensitive receptor in residential and parkland sites, according to the OMEE, is a child aged six months to four years. Assuming 64 % of a child's lead intake is derived from soil, a lead intake level of concern of 1.85 μg/kg, a body weight of 13 kg and a soil consumption rate of 80 mg per day, the guideline is calculated to be 200 ppm. This means that if a child weighing 13 kg ingests 0.08 g of soil each day, then a soil-lead concentration of 200 ppm would limit the child's lead intake to less than 1.2 μg/kg/day (or 64 % of the lead intake level of concern).

The OMEE recommends that special consideration should be given to play areas, which attract large numbers of children. The play activities "normally encountered in these areas can result in increased soil ingestion which in turn increases the risk of exposure to lead. For this reason, special consideration should be given to ensuring that lead levels in covering soil used for play areas is limited to the greatest extent possible. For special situations such as these, soil quality consistent with rural background soil should be used wherever possible" (OMEE, 1993: 32).

Yet, regardless of the concentration, the mere presence of lead in the environment does not, by itself, necessarily pose a risk to human health. It is the combination of lead concentration and form, in relation to human activities, that may endanger health. Many factors can influence whether, and how much, lead in soil is actually absorbed into humans' blood (Wixson and Davies, 1993). The bioavailability of lead, for example, can influence whether soil-lead is absorbed. Behavioural factors such as fingernail biting, dirty clothes, and mouthing, are also significant in affecting blood-lead levels. An analysis of exposure pathways demonstrated that children tend to have higher blood-lead levels if they live or play in areas with higher percentages of bare soil (Hilts, 1996).

Several studies have found that the blood-lead levels in children living in urban areas and smelter and mining communities vary considerably, even when total lead concentrations in soil are similar (Davis et al., 1993). Although many factors may modify a human's uptake of lead from soil, the link between soil and blood-lead levels is distinct (Rabinowitz, 1993).

### 2.7.2 Human Health Effects of Lead

Lead is a poisonous substance and has no known physiological role in the human body (Hilborn and Still, 1990). Lead enters the human body primarily via inhalation and ingestion. The lungs retain lead more efficiently than the gastrointestinal tract (Laws, 1981). Only 5 to 10 % of all ingested lead moves out of the digestive tract and into the blood, whereas 30 to 40 % of lead inhaled into the lungs reaches the bloodstream (Stoker and Seager, 1976). Once absorbed into the bloodstream, lead is transported to all parts of the body, primarily by red blood cells.

The majority of lead which is absorbed passes to the bones and teeth, where it is metabolized in a similar fashion to calcium. Lead is similar in size to the calcium ion and the body perceives lead as having many calcium-like characteristics (Flegal and Smith, 1995). Absorbed lead becomes incorporated into the lattice of the bone apatite crystal (Stoker and Seager, 1976). Bone-accumulated lead may be remobilized and sent to other parts of the body long after the initial absorption. Absorption by any route is slow and prolonged exposure is required for the development of symptoms. There is no feedback mechanism limiting the absorption of lead, as the body burden of lead does not influence its absorption (Ragan, 1983). The health effects associated with high levels of lead can be acute or chronic. Acute, or severe, lead poisoning results from exposure to very high levels of lead, often over a short period of time, and is a medical emergency. Chronic lead poisoning, on the other hand, results from prolonged exposure to lower levels of lead. The signs of chronic lead poisoning are much less obvious than the signs of severe lead poisoning.

Severe lead toxicity, a focus of medical research in the 1960s, causes brain disease, kidney damage, coma or heart failure (Brinkmann, 1994; Madhavan et al., 1989; Meade et al., 1988; Davies and Wixson, 1986). Estimates vary concerning the exact level of lead in the blood necessary to cause symptoms of clinical lead poisoning. However, anaemia is generally considered the first visible sign. Anaemia results because lead interferes with the synthesis of heme, a major constituent of haemoglobin. As a result, the life span and average number of red blood cells in the circulating blood are reduced, causing anaemia (Stoker and Seager, 1976). Other symptoms of severe lead poisoning include abdominal pains, vomiting, neuro-muscular weakness, behavioural changes, lack of muscle co-ordination and convulsions (Forstner and Wittman, 1979).

During the 1970s, it was accepted that chronic exposure to lead and its cumulative effects were harmful (Madhavan et al., 1989). It is now recognized that lead is a cumulative poison, slowly excreted, causing symptoms which are usually chronic. As a result, more recent research has focused on low-levels of lead exposure and chronic lead poisoning, which can lead to neurological disturbance, peripheral nerve dysfunction and impaired heme synthesis (OMEE, 1993; Davies and Wixson, 1988).

Cambra and Alonso (1995) concluded that the population at highest risk for the well-known toxic effects of lead are children aged one to six. Children are more sensitive to toxic effects of lead for the following reasons. First, the central nervous system is especially vulnerable to toxins during early postnatal development (OMEE, 1993). Secondly, children absorb lead more readily than adults. Children absorb 50 % of the lead they ingest, compared with 5 to 10 % absorption for adults (Mielke et al., 1984). Thirdly, children's lead intake on a body weight basis is greater because of their smaller body size (OMEE, 1993).

In the 1980s, research focused on the effects of low-level lead exposure on children's health. Research indicated that children's exposure to lead, at levels previously thought to have no adverse effects, may have lasting impacts (Alexander et al., 1993). In recent years, the blood-lead level associated with the first adverse effects in children was first lowered from 25 to 15 μg/dL, then later to 10 μg/dL (OMEE, 1993). However, it is also possible that adverse health effects may result from blood-lead levels less than 10 μg/dL in children (OMEE, 1993). Several studies have linked low-level lead exposure in childhood with disturbances in early physical and mental development and in later intellectual functioning (Berglund et al., 1994). For example, Needleman (1990) found that low-dose lead exposure impairs the IQ of children. In addition, the American Agency for Toxic Substance and Disease Registry reported that low doses of lead are detrimental to the central nervous system of infants and children (Elhelu et al., 1995).

Recent studies have suggested that actual exposure to lead in children and eventual lead poisoning may be influenced by sociodemographic characteristics. For example, Mahaffy et al. (1982) provided data revealing that as family income increased, mean blood-lead concentration in young children decreased (in Elhelu et al., 1995). The possible explanation for this correlation is that wealthier parents are able to afford day care or other educational facilities, and to plan various activities for children. Elhelu et al. (1995) examined the role of sociodemographics in childhood lead poisoning in Washington, D.C. The authors concluded that demographic characteristics, such as lower education, lower income and increased proportion of single-parent families, appeared to enhance the distribution of lead poisoning. It has also been reported that the effects of low-level lead exposure are related to the child's quality of nutrition (Wixson and Davies, 1993). More lead is absorbed if a child has no food in his/her stomach or has a calcium deficiency.

Factors such as parental supervision, behaviour (eg. pica, personal habits) and nutritional status of the children can influence whether lead in soil is absorbed and whether health problems will result (Wixson and Davies, 1993; Chaney et al., 1989). A survey conducted in Charleston showed that most children with lead poisoning were poorly supervised and participating in pica (Fairey and Gray, 1970). Chaney et al. (1989) state that the child at highest risk of soil-lead is a poorly supervised child who regularly plays in lead-rich soil, has pica for soil, and has poor nutrition.

## 2.8 SUMMARY

Lead cycles through the environment until it reaches a geochemical sink. Soil and sediment are the ultimate sinks for lead. While lead occurs naturally, human activities have increased the concentrations in the environment. A great deal of research has focused on the distribution and concentration of lead in soil and sediment. It is generally found that lead concentrations are higher at the surface than at depth. Limited research has been conducted on the distribution of lead in the Arctic. Most studies have focused primarily on waste-disposal sites and total lead concentrations.

Lead poses a health hazard to humans, and children are particularly vulnerable to the toxic effects of lead. Soil and sediment are two pathways along which lead can reach humans and impact health. The combination of concentration and chemical form of lead, in relation to human activities, may endanger health. Several studies have found links between lead in soil and high lead levels in humans. Many of these studies have found the links by using systematic sampling along grids or transects, and stratified sampling, targeting areas where humans may potentially contact lead contaminated soil. Many factors influence whether lead is absorbed into humans' blood. For example, children who live or play in areas with high percentages of bare soil tend to have higher blood-lead levels.

# CHAPTER 3: METHODS

## 3.1 INTRODUCTION

This chapter describes the study area and methods used to collect and analyze the soil and sediment samples. Section 3.2 describes the study area. Section 3.3 describes the field work component of the thesis, including sample design and collection techniques. Section 3.4 describes the laboratory component, including sample preparation, and analyses of bioavailable and total lead concentrations and grain size. Section 3.5 describes the methods of data analysis used to present the results.

## 3.2 STUDY AREA

Iqaluit is located at 64°45' N 68°31' W on southern Baffin Island. The town lies on the eastern side of the Koojesse Inlet, where the Sylvia Grinnell River flows into Frobisher Bay. Southern Baffin Island, including Iqaluit, is part of the Canadian Shield and is dominated by Precambrian crystalline bedrock of the Churchill Structural province (Andrews, 1989). The bedrock in Iqaluit consists of a variety of metamorphic rocks, such as granite, migmatite and quartz-feldspar gneissic rocks (Blackadar, 1967). The subsoil consists of a mantle of glacial drift and the overburden contains nutrient poor silty sand, sand, gravel and boulders (Environmental Services, 1992). The topography and structural geology of the study area follow a northwest-southeast trend, with parallel rock ridges up to 135 m high interspersed with valleys of varying width. Drainage follows a similar pattern.

Iqaluit lies within the low arctic tundra zone. Soils are silty in character, and generally have little, if any profile development (Edlund, 1991; Linell and Tedrow, 1981). As a growth medium, soils are nutrient-poor, cold, shallow, and saturated in low areas. Tundra vegetation prevails and is limited to dwarf shrubs, such as arctic willow, lichens, herbs, mosses, grasses, sedges and low flowers (Wiken, 1986). Where suitable soils are not available for vegetation, barren bedrock exists.

For eight months of the year, mean daily temperatures in Iqaluit are below freezing. In January, the mean daily temperature is -25.8°C, and in July, the mean daily temperature is 7.7°C (Environment Canada, 1990). The mean annual rainfall is 192.9 mm and the mean annual snowfall is 2568 mm. The high precipitation value for an Arctic latitude reflects the strong marine influence. The average windspeed is 16 km/h, with dominant wind directions from the northwest for most of the year, and from the southeast for June, July and August.

The hydrological cycle is strongly influenced by the cold environment, but becomes more active during the short summer period. The ice on Frobisher Bay begins to melt around the middle of July (BRHB, 1994). Spring thaw and active-layer development begin around the middle of June (BRHB, 1994); while the depth of the active layer varies, it may reach 1.8 m (Environmental Services, 1992).

Specific sites were selected for sampling (Figure 3.1), and will be further discussed in Section 3.3.1. These sites were chosen because previous research has demonstrated that elevated lead levels are present (eg. ESG, 1995). Sylvia Grinnell Park is a 148 hectare territorial park located between the airport and the Sylvia Grinnell River. It is a favourite camping, hiking and fishing spot for the local population. A waste disposal site (West 40) is located on the cliffs within the park, overlooking the river. The site was used by the US

Military for domestic garbage, construction and maintenance materials, vehicles and electrical equipment. Two distinct debris areas exist: a pile of vehicles east of the main dump and the main dump on the cliff face.

The Upper Base, a former US military communications site, is situated on top of a mountain overlooking Iqaluit. The Upper Base was constructed in the 1950s as part of the American radar surveillance system. In 1974, the base was abandoned but buildings and equipment were left intact (Environmental Services, 1992). The abandoned site was scavenged for building materials, and used for target shooting and games (ESG, 1995). Because of the potential for contaminants from the site to leach into Lake Geraldine, the town's water supply, the site has recently been tested and cleaned up.

A metal dump, North 40, is located in a valley northwest of the town (Environmental Services, 1992). Situated on 30 hectares of fluvial plain, the dump receives a great deal of runoff from the surrounding hills and has a high water table. Culverts were built to control drainage through the dump, and to divert water into the Koojesse Inlet. A small creek, referred to as North 40 Creek, receives runoff from the Metal Dump, flows through the town and empties into Koojesse Inlet. Debris at the dump includes a plane fuselage, metal drums, household materials, such as refrigerators, and construction debris. The site of the North 40 metal dump is also the source of the town's granular material.

The built-up areas of Iqaluit and Apex, a satellite community 5 km southeast, have not previously been tested for lead. These areas are predominantly residential, with some industrial and commercial land uses in Iqaluit. In these built-up areas, vegetation cover is limited. The playgrounds and lots on which buildings are constructed have little or no ground cover, and bare soil surfaces dominate. In 1978, approximately one-third of the road system was paved (UMA, 1996). However, the majority of roads in Iqaluit and Apex are graded with gravel surfaces. Some residents have complained during the summer months that the dust from the roads is harmful (BRHB, 1994). Water is spread occasionally to keep the dust down.

## 3.3 FIELDWORK

A scientific research licence from the Nunavut Research Institute was obtained for this project. The field component was completed during five weeks in the summer, from July 4 to August 9, 1996. This time period was chosen because the snowcover had melted, active layer formation had begun, and rivers, streams and runoff were active. During summer, children play outside and are exposed to soil. In the following subsections, sample design and collection techniques are described.

### 3.3.1 Sample Design

The sample design was developed after reviewing the literature, examining topographic maps and air photos and completing an initial field reconnaissance. Systematic sampling, using grids and transects, as well as deterministic sampling strategies were employed. In deterministic sampling, areas of human activities and areas likely to be contaminated were selected. The sample areas are shown on Figure 3.1.

First, samples were collected outside the built-up area of Iqaluit to reveal natural background levels. To identify high lead concentrations in the soil or sediment, or lead

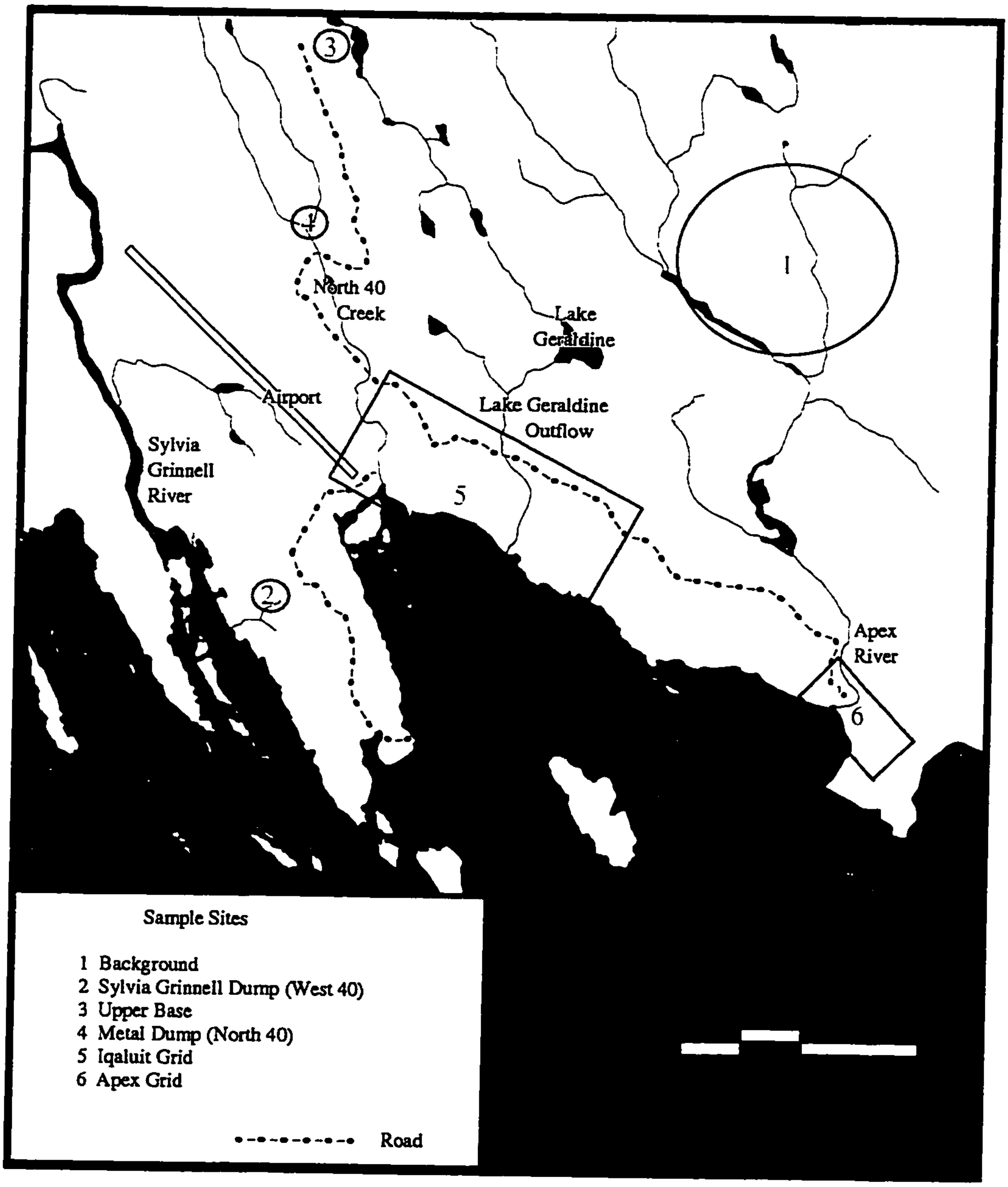


Figure 3.1 Map of Study Sites

contamination, samples from potentially uncontaminated areas were collected and analyzed for comparison. Soil samples were collected systematically along transects at 100 m intervals. Locations of the transects were chosen based on distance from human activities and accessibility. Sediment samples were also collected from streams outside the built-up area at 50 m intervals. Where possible, sediment samples were collected in depositional areas of streams, such as mid-channel bars and point bars.

Second, areas thought to have high lead concentrations were targeted for comparison. The sites included the following: Sylvia Grinnell Dump (West 40), Upper Base and Metal Dump (North 40). Soil samples were collected from each site and sediment samples in runoff were collected from the Metal Dump (North 40 Creek).

Systematic sampling was conducted within the built-up area of Iqaluit, adjacent to the Koojesse Inlet. This area is bounded by rolling hills on three sides and receives a substantial amount of runoff, particularly from the northwest slopes. Runoff passes through the built-up area before flowing into the Inlet. The town map was overlaid with a grid, approximately 200 x 200 m, covering 2 $km^2$. Samples were collected at each grid intersection (Figures 3.2). The grid was used to promote complete coverage and representativeness of soils within the area and the 200 m interval yielded a significant number of samples (> 30).

Site-specific sampling was also conducted within the grid area of Iqaluit. Sites where humans, particularly children, may contact contaminated soil and sediment were targeted. Samples were collected from three schools: Joamie (Play1), Nakasuk (Play5B), and Inuksuk High School (Play6). Samples were also collected from one softball diamond (Play5A) and

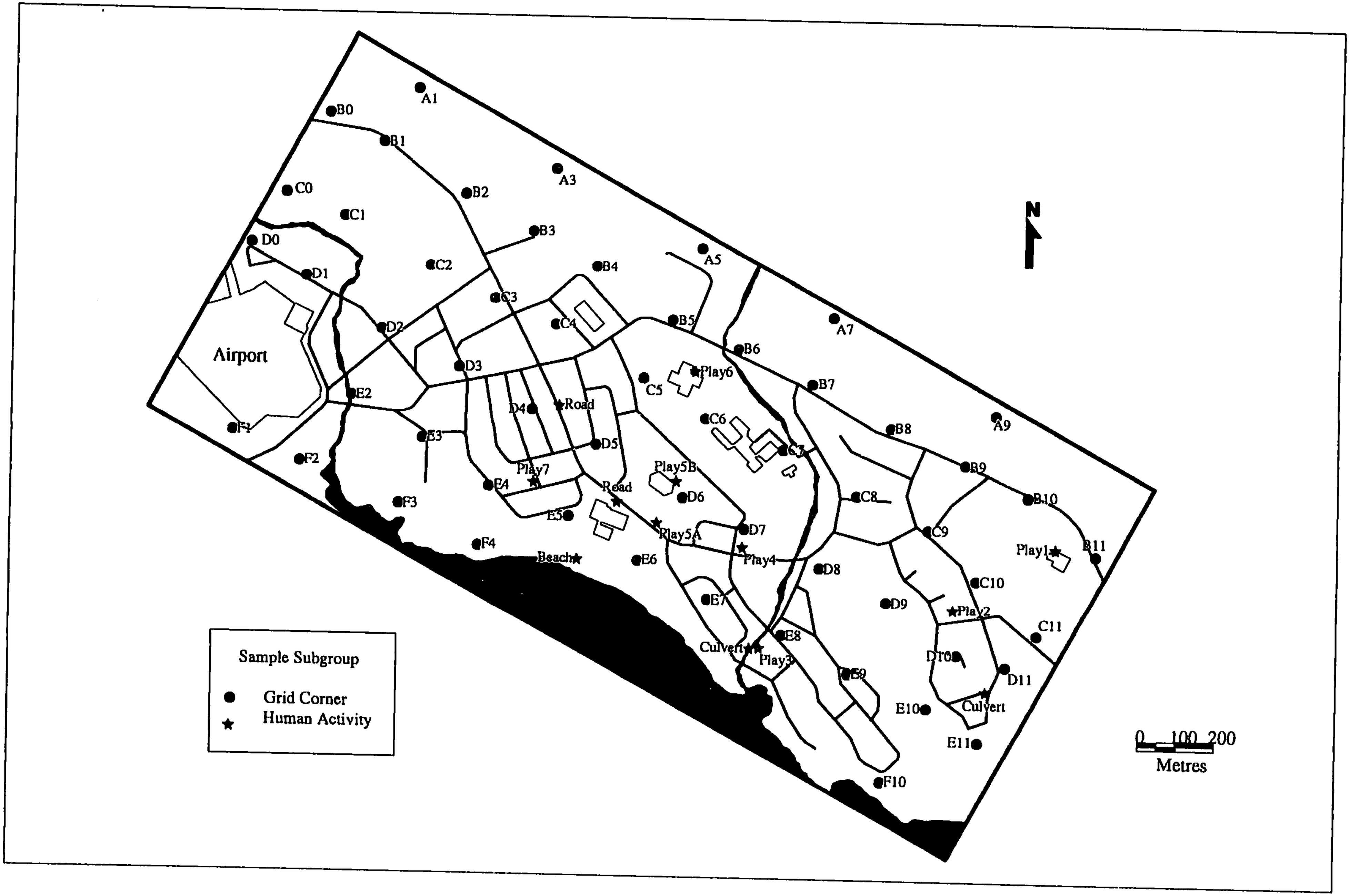


Figure 3.2 Map of Iqaluit Grid A... Grid C...

five municipal playgrounds: Happy Valley (Play2), Ikaluit (Play3), Astro Hill (Play4), Lower Base (Play7) and Tundra Valley (Play8). Samples were also collected from two culverts, popular play areas for children. Finally, samples were collected from the roads. Children play on the roads where fine-grained materials are mobilized by vehicles and inhaled by humans. Road samples were taken in front of the post office and the Northern store, where people tend to congregate.

Sediment samples were collected along two streams, North 40 Creek and Lake Geraldine Outflow, and from runoff channels within the Iqaluit grid area (Figure 3.3). North 40 Creek receives runoff from the Metal Dump (North 40) before flowing through the grid area and emptying into the Koojesse Inlet. The stream is shallow and the bed is comprised mainly of gravel, cobbles and boulders. The Lake Geraldine Outflow drains from the town's reservoir when the dam is full, and flows through the town before entering the Koojesse Inlet. The outflow drains over grass, sand, cobbles and boulders. Where possible, sediment samples were collected at areas of deposition.

Apex was systematically sampled (Figure 3.4). The town map was overlaid with a 200 by 200 m grid and samples were collected at the grid intersections. The school in Apex, Nanook (Play9), was also sampled.

### 3.3.2 Sample Collection Techniques

Field notes were made at each site. The name of the site, sample number, time and date of collection, weather conditions, land use, topography, and drainage (where visible) were recorded. Where sediment samples were collected, water temperature and pH were

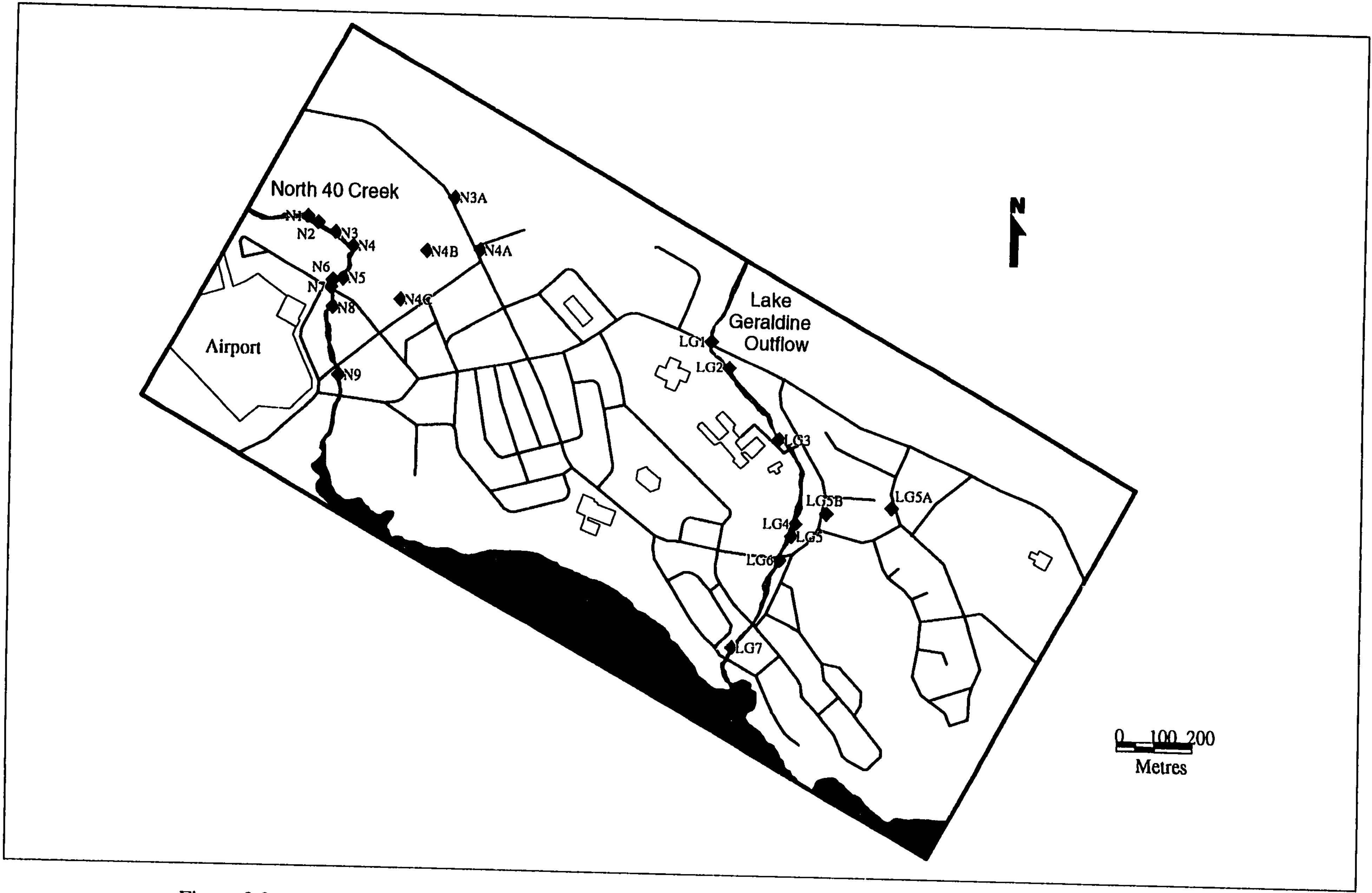


Figure 3.3 Map of Iqaluit Grid Area: North 40 Creek and Lake Geraldine Outflow Sediment Sample Sites

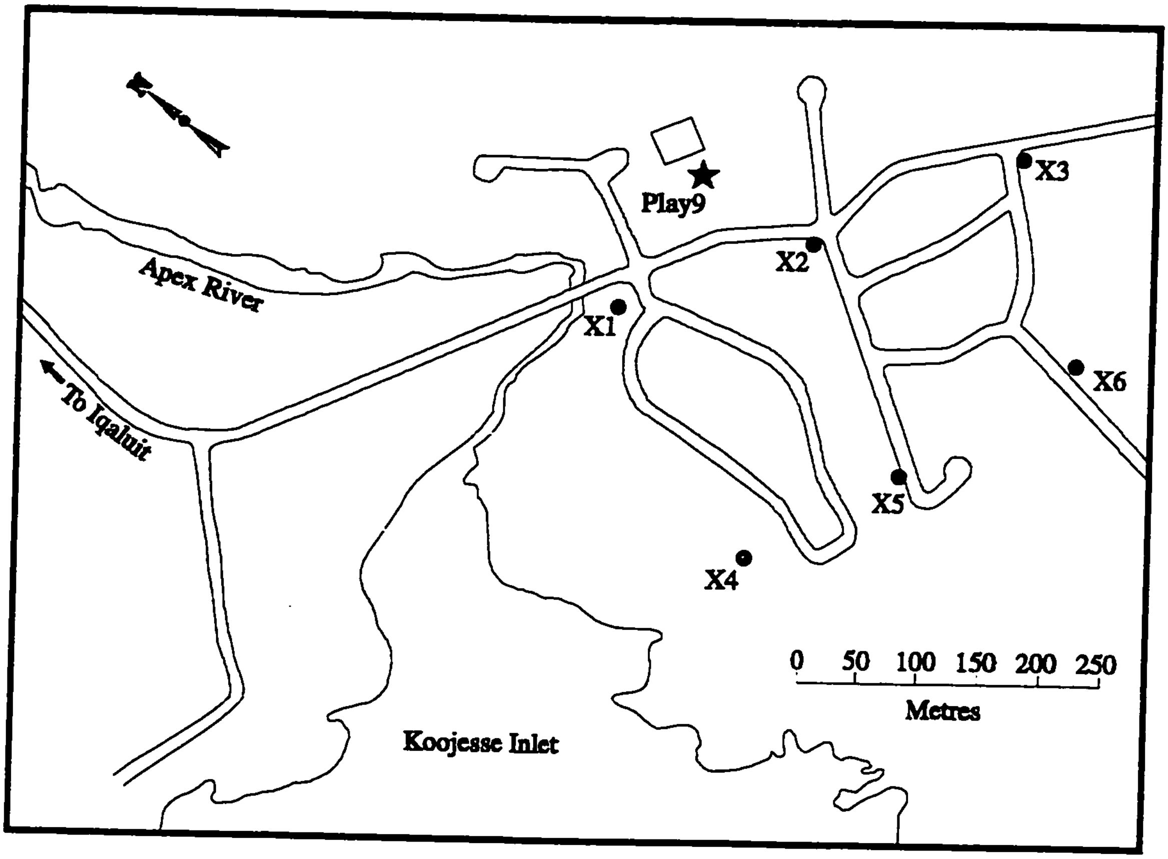


**Figure 3.4 Map of Apex Grid Area: Sample Sites**

recorded. The soil and sediment samples were also qualitatively described with respect to texture, consistency, and odour. Munsell soil colour charts were used to describe colour. The location of several sites was recorded using a GPS. Due to scattering of the satellite signals, several GPS readings taken at a fixed location may appear to "wander". When the data are downloaded, the readings appear as a cluster of points rather than one single point. Consequently, at each recorded site, several GPS readings were taken and the actual UTM coordinates were calculated later.

Samples were collected using plastic grab bags. Surface soil samples were collected at each sample site and subsurface soil samples were collected at random intervals. The depth to which the profiles were dug depended on the thickness of the soil profile. Because much of the soil in the area is shallow and because of the limited mobility of lead through the soil column, the maximum sample depth was 20 cm.

Given the ubiquitous nature of lead, several precautions were taken to avoid, or at least minimize, contamination. Samples contacted only materials having no, or intrinsically low, levels of trace metals, such as plastic bags and a Teflon shovel. In addition, samples were collected downwind to avoid contamination from clothing. Each sample collected was immediately sealed to avoid loss or contamination, double (and in some cases, triple) bagged and individually labelled with a sample number. The samples were kept in plastic bags in sealed containers until analysis. Mudroch and MacKnight (1991) state that sediment samples intended for analysis after oven drying can be stored in plastic bags at room temperature.

## 3.4 LABORATORY ANALYSIS

Upon arrival at the laboratory, the sample numbers recorded in the field were converted to laboratory sample numbers, to prevent any bias during the laboratory procedures. The laboratory component of the research was undertaken at Wilfrid Laurier University and Bondar-Clegg Laboratory. The procedures for metal analysis of sediments are generally applicable to soils, and therefore the same laboratory procedures were used for both. Samples were analyzed for total lead and bioavailable lead concentration. Grain size analysis was performed on some of the samples.

During sample preparation, contamination can be a serious source of error. As a result, several steps were also taken in the laboratory to avoid, or at least minimize, contamination. Sieves were made from plastic yogurt containers and plastic pipe, which were tested for lead prior to sieve construction. These materials were soaked in a 20 % HCl acid bath for 24 hours and the solution was analyzed for lead by atomic absorption spectrometry. The solution was found to contain no detectable lead. The yogurt containers and plastic pipe were covered with 63 μm Nytek screening, which was taped around the outside. The sieve pans and lids were constructed of plastic yogurt containers and Tupper Ware, which were also tested and found to contain no detectable lead. The samples were weighed with plastic spoons. All glassware and instruments were triple washed with 20 % HCl and rinsed with ultrapure deionized water to avoid contamination. The laboratory benches, scale and oven were consistently washed to ensure the surfaces were clean. A lab coat, gloves and mask were worn throughout the sample preparation phase.

### 3.4.1 Sample Preparation

The following steps were taken to prepare for both total lead and bioavailable lead analysis. Samples were coned and quartered. Representative subsamples were oven dried at 110°C for 24 hours. Oven drying is appropriate for determination of trace elements in sediment (Mudroch and Azcue, 1995). The dried samples were then ground gently with mortar and pestle to mix and disaggregate the particles. Next the samples were sieved using the plastic sieves constructed of 63 μm Nytek screen. The fraction less than 63 μm was analyzed because of the previously discussed relationship between decreasing grain size and increasing lead concentrations, the significance of this grain size in fluvial transport, and the adherence of this grain size to human hands.

### 3.4.2 Bioavailable Lead

In this research, bioavailable lead is operationally-defined as 0.5N HCl extractable and determined by methods described by Environment Canada (1979). Ten grams of the <63 μm size fraction was weighed and placed in a 125 mL erlenmeyer flask, and 100 mL of 0.5N HCl, measured volumetrically, was added[1]. The hydrochloric acid solution was prepared by diluting concentrated HCl, measured by weight, with ultrapure deionized water. The flasks were sealed with parafilm and shaken at room temperature in a mechanical shaker at low speed for 16 hours. The solution was filtered by suction using a 0.45 μm membrane

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[1] The ratio of acid solution to dried sieved sample was constant at 10:1. In some cases, as with coarse-grained samples, the amount of dried sieved sample weighed was less than 10 g. In such instances the amount of acid solution was reduced from 100 mL. For example, 8 g of dried sieved sample was mixed with 80 mL of 0.5N HCl.

filter. Duplicate analysis on 10 samples (approximately 1 in 20) was performed to obtain a precision of the analysis.

The supernatant was analyzed using atomic absorption spectrometry. A Perkin Elmer (Model 3100) atomic absorption (AA) unit with air-acetylene flame was used. The impact bead was installed to lower the detection limit to 0.2 mg/L. Integration time was set at 10 seconds to improve precision. The AA was calibrated using 1000 ppm lead stock diluted with 0.5 N HCl solution to make standards of 0.20, 0.40, 1.00, 3.0 and 5.00 ppm, which fall in the linear range. Every twenty samples, the AA was recalibrated with known standards.

The extractable lead concentration was calculated using equation [3.1]:

$$M = (SV) / X \qquad [3.1]$$

where, M = concentration of extractable metal in sediment (mg/kg),
S = concentration of metal in solution (mg/L),
V = total volume of solution in which the sample is dissolved (L), and
X = weight of dry sediment used (kg).

### 3.4.3 Total Lead

The samples for total lead analysis were prepared in the laboratory at Wilfrid Laurier University using the sample preparation steps described in Section 3.4.2. This was done to maintain consistency in sample preparation between total and bioavailable lead analysis and to reduce costs. Due to financial constraints, composite samples, based on land use groups, were submitted to provide average total lead values for sample areas. Approximately 2 g of each dried, sieved sample was weighed, combined and mixed thoroughly with other samples from the same land use group. Individual samples for total lead analysis were chosen randomly from bioavailable lead samples. The prepared samples were submitted to Bondar-Clegg Laboratory for total lead analysis. The technique employed was open digestion using hydrofluoric, nitric and perchloric acids, followed by atomic absorption spectrometry. The detection limit is 2 ppm.

### 3.4.4 Grain Size Analysis

Four samples selected for grain size analysis included the following: tundra, stream sediment, roads, and playgrounds. The samples were dry sieved in a mechanical shaker to determine the proportion of sample less than 63 μm.

## 3.5 DATA ANALYSIS

The data are organized into sample subgroups based on land use. The subgroups include: background, Sylvia Grinnell Dump (West 40), Upper Base, Metal Dump (North 40), Iqaluit grid area and Apex grid area. Within the Iqaluit grid area, samples are further sorted into stream sediment, grid corners and areas of human activity. Samples are sorted into grid corners and playground, within the Apex grid area.

Bioavailable lead concentrations are expressed to one decimal place and all concentrations are reported in parts per million (ppm). The range, mean, and standard deviation of lead concentrations in each sample subgroup are presented. The median, which is a better representation of central tendency than mean values for positively skewed data, is also presented.

Before performing additional statistical analysis, the data were normalized through logarithmic transformation. Davies (1989) states that as a general rule, all soil-lead data should be log-transformed before statistical analysis. Using the log-transformed data, F-tests, t-tests, and regression and correlation analyses were performed, at a 0.05 confidence level. Statistical analysis was performed using QuattroPro and SPSS.

Total lead concentrations are compared to the NWT soil-lead guidelines. To address the potential risk to human health, total lead concentrations are also compared to the Ontario Ministry of Environment and Energy (OMEE) recommended guidelines. For comparison, the sample subgroups are categorized as follows: Sylvia Grinnell Dump (West 40) is a commercial/industrial and residential/parkland site; Metal Dump (North 40) and Upper Base are commercial/industrial sites; Iqaluit and Apex grid areas are residential sites. The stream sediment in Iqaluit is compared to the Ontario Provincial Aquatic sediment quality guidelines.

The town map of Iqaluit was digitized in MapInfo, using control points recorded with the GPS. When downloaded, GPS readings from each recorded sample site appeared as clusters of points. The UTM coordinates of each sample site were derived by calculating the geometric mean of the points. Four control points, using the GPS data, were used to digitize the map. Once in MapInfo, the sample sites in the grid area were georeferenced with UTM coordinates (x, y). Each sample site was also assigned a z-value, equalling bioavailable lead concentration. The x, y, and z co-ordinates were imported to Surfer, and the lead data were kriged (a common method used to interpolate z-values in locations where no data exist) to produce an isoline map. The map error is less than 40 m. The map of Apex was scanned using CorelTrace and sample sites were added in CorelDraw.

# CHAPTER 4: RESULTS AND DISCUSSION

## 4.1 INTRODUCTION

This chapter presents the research findings interspersed with discussion. Section 4.2 addresses the errors in the data. Section 4.3 presents bioavailable lead concentrations (operationally-defined as 0.5N HCl extractable). Background lead concentrations are compared with different sample subgroups, such as Sylvia Grinnell Dump (West 40) and the Iqaluit grid area. Section 4.4 presents total lead concentrations by comparing them to environmental guidelines. Section 4.5 discusses the relationship between bioavailable and total lead concentrations in the study area. Sections 4.6 and 4.7 present lead concentrations at depth and results of grain size analysis.

## 4.2 ERRORS

Potential error in data results from sampling protocol, sample preparation and chemical analysis. Contamination during sample preparation can introduce error and several precautions were taken to avoid or minimize contamination in the field and the laboratory. Duplicate analyses were performed to assess errors in the data derived from sample preparation and determination stages.

### 4.2.1 Comparison of Sample Preparation

To initially assess the quality of sample preparation, two samples prepared at the laboratory at Wilfrid Laurier University (WLU) were compared with the same samples prepared at Bondar-Clegg Laboratory (B-C Laboratory). The two samples were randomly chosen and then coned and quartered. Two-quarters of each sample were sent to B-C Laboratory for sample preparation (drying, grinding and sieving) and lead analysis. The remaining two-quarters were prepared at WLU (dried, ground and sieved) and then sent to B-C Laboratory for lead analysis. The results of duplicate analyses are shown in Table 4.1. The data indicate that sample preparation from the two laboratories did not differ markedly. The coefficients of variation (standard deviation divided by the mean times 100 percent) of the two duplicate samples were 13 and 15 %. Consequently, all sample preparation was conducted at WLU utilizing standard quality controls with appropriate duplicates and blanks.

Table 4.1 Total Lead Concentration (ppm): Comparison of Sample Preparation at Wilfrid Laurier University and Bondar-Clegg Laboratory

| Sample Number | Concentration from WLU | Concentration from B-C | Mean | Standard Deviation | Coefficient of Variation |
|---|---|---|---|---|---|
| 1 | 49 | 61 | 55 | 8 | 15 |
| 2 | 107 | 89 | 98 | 13 | 13 |

4.2.2 Precision

Precision refers to the repeatability of a measurement (Rollinson, 1993). To quantitatively assess precision, duplicates of ten samples were prepared and analyzed. Precision is defined by the coefficient of variation. Table 4.2 presents the coefficient of variation for each duplicate analysis.

Table 4.2 Bioavailable Lead Concentrations (ppm): Duplicates

| Sample Subgroup | Sample Number | Concentration (ppm) | Concentration (ppm) | Mean | Standard Deviation | Coefficient of Variation (%) |
|---|---|---|---|---|---|---|
| Background | 25 | 4.8 | 5.3 | 5.1 | 0.4 | 7.8 |
| Background | 37 | 3.8 | 4.3 | 4.1 | 0.4 | 9.8 |
| Iqaluit - Stream Sediment | N6 | 6.9 | 8.1 | 7.5 | 0.8 | 10.7 |
| Iqaluit - Stream Sediment | LG4 | 28.4 | 28.7 | 28.6 | 0.2 | 0.7 |
| Iqaluit - Grid Corner | A3 | 10.0 | 13.0 | 11.5 | 2.1 | 18.3 |
| Iqaluit - Grid Corner | B6 | 34.3 | 39.0 | 36.7 | 3.3 | 9.0 |
| Iqaluit - Grid Corner | C9 | 16.0 | 16.6 | 16.3 | 0.4 | 2.5 |
| Iqaluit - Grid Corner | D13 | 4.4 | 5.1 | 4.8 | 0.5 | 10.4 |
| Iqaluit - Grid Corner | F2 | 67.0 | 81.8 | 74.4 | 10.5 | 14.1 |
| Metal Dump - North 40* | MDR3 | 18.1 | 26.7 | 22.4 | 6.1 | 27.2 |

* Note: Two separate samples were collected at this site, resulting in a large coefficient of variation. Unlike the preceding 9 coefficient of variations, which were each calculated from one sample which was coned and quartered, the 27.2 % represents the coefficient of variation of two separate samples taken at the same location. Therefore, the percentage is a reflection of spatial variability, as well as laboratory precision.

## 4.3 BIOAVAILABLE LEAD CONCENTRATIONS

### 4.3.1 Background

Thirty-eight soil and sediment samples were collected outside the built-up area in Iqaluit to determine natural background lead levels. Bioavailable lead concentrations of the background samples are summarized in Table 4.3, and range from 2.8 to 15.4 ppm. The mean bioavailable lead concentration is 6.9 ppm, with a standard deviation of 3.3 ppm. In Northern environments, lead concentrations above background are assumed to indicate anthropogenic activities. In this thesis, any sample site exceeding 10 ppm will be considered lead-enriched. Bioavailable lead concentrations from the background group are used throughout this section to test the research hypothesis that elevated levels of lead (ie. above natural background concentrations of 10 ppm) are present in the soil and sediment in the study area.

Table 4.3 Bioavailable Lead Concentrations (ppm): Based on Sample Subgroup

| Sample Subgroup | Number of Samples | Minimum | Maximum | Median | Mean | Standard Deviation |
|---|---|---|---|---|---|---|
| Background | 38 | 2.8 | 15.4 | 6.1 | 6.9 | 3.3 |
| Sylvia Grinnell Dump - West 40 | 9 | 8.0 | 1185.3 | 70.0 | 189.3 | 376.5 |
| Upper Base | 5 | 9.5 | 62.0 | 19.4 | 25.7 | 20.8 |
| Metal Dump - North 40 | 9 | 2.1 | 60.0 | 19.3 | 21.2 | 16.8 |
| Iqaluit - Grid Area | 101 | 3.5 | 122.0 | 13.4 | 21.8 | 20.6 |
| Apex - Grid Area | 7 | 6.7 | 401.8 | 29.9 | 93.6 | 140.7 |

4.3.2 Sylvia Grinnell Dump (West 40)

Nine soil samples were collected from the Sylvia Grinnell Dump. Table 4.3 shows that bioavailable lead concentrations from this land use group range from 8.0 to 1185.3 ppm, and have a median concentration of 70.0 ppm.

Figure 4.1 graphically compares bioavailable lead concentrations of the Sylvia Grinnell Dump with the background concentrations. An F-test reveals that the variance of the Sylvia Grinnell Dump land use group is not similar to the variance of the background land use group (F = 10.354; P = 0.001), and, therefore, the two groups are significantly different. A t-test, assuming unequal variance, rejects the null hypothesis (t = -5.009; P = 0.001). Bioavailable lead concentrations at the Sylvia Grinnell Dump (West 40) are significantly greater than background levels.

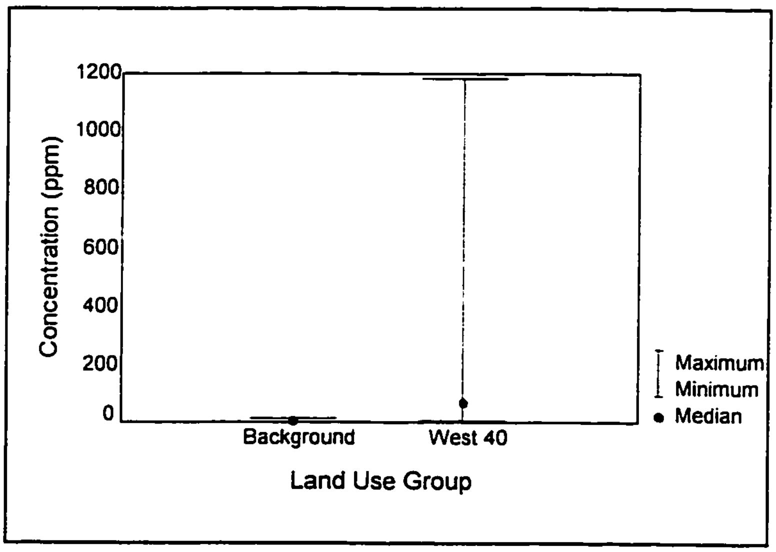


Figure 4.1 Bioavailable Lead Concentrations: Background and Sylvia Grinnell Dump (West 40)

4.3.3 Upper Base

Five soil samples were collected from the Upper Base. Table 4.3 shows that bioavailable lead concentrations range from 9.5 to 62.0 ppm, with a median of 19.4 ppm. Figure 4.2 shows the difference in bioavailable lead concentrations at the Upper Base and background. An F-test fails to show a significant difference in the variances of the Upper Base and background land use groups, at the 95 % confidence level ($F = 2.503$; $P = 0.192$). This may be the result of a small sample size from the Upper Base. A t-test, assuming equal variance, rejects the null hypothesis ($t = -5.414$; $P < 0.001$). Therefore, bioavailable lead concentrations at the Upper Base are significantly greater than background concentrations.

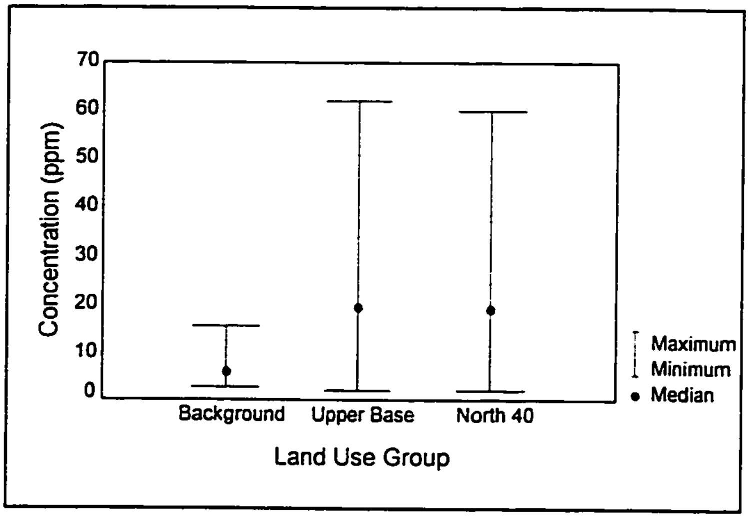


Figure 4.2 Bioavailable Lead Concentrations: Background, Upper Base and Metal Dump (North 40)

#### 4.3.4 Metal Dump (North 40)

Within the Metal Dump land use group, nine samples were collected and analyzed. Table 4.3 displays bioavailable lead concentrations, ranging from 2.1 to 60.0 ppm with a median of 19.3 ppm. Figure 4.2 illustrates the difference in lead concentrations between the Metal Dump (North 40) and background. An F-test indicates that variances of the Metal Dump and background groups are not similar ($F = 5.235$; $P = 0.006$). The results of a t-test reject the null hypothesis ($t = -2.942$; $P = 0.007$), indicating that bioavailable lead concentrations at the Metal Dump are significantly greater than background concentrations.

The Metal Dump land use group includes samples taken from the dump (termed "Metal Dump proper"), as well as sediment samples (termed "runoff") taken from its ditches. Table 4.4 shows bioavailable lead concentrations from the Metal Dump proper and from the runoff. Lead concentrations from the Metal Dump proper are higher than concentrations in the runoff. This finding suggests that there is little movement of particulate lead in runoff from the Metal Dump to the ditches.

Table 4.4 Bioavailable Lead Concentrations (ppm): Metal Dump Proper and Runoff

| Description | Number of Samples | Minimum | Maximum | Median | Mean | Standard Deviation |
|---|---|---|---|---|---|---|
| Metal Dump - Proper | 5 | 14.6 | 60.0 | 23.1 | 27.6 | 18.5 |
| Metal Dump Runoff | 4 | 2.1 | 26.7 | 11.9 | 13.2 | 11.8 |

### 4.3.5 Iqaluit Grid

One-hundred and one soil and sediment samples within the grid area were analyzed for bioavailable lead concentration, and the concentrations are summarized in Table 4.3. Samples were collected from the following areas: stream channels, corners of the grid squares, and areas of human activity. Table 4.5 summarizes bioavailable lead concentrations from these three groups in the Iqaluit grid area.

Table 4.5 Bioavailable Lead Concentrations (ppm): Iqaluit Grid

| Description | Number of Samples | Minimum | Maximum | Median | Mean | Standard Deviation |
|---|---|---|---|---|---|---|
| Stream Sediment | 25 | 4.4 | 56.5 | 9.4 | 19.3 | 16.4 |
| Grid Corners | 62 | 3.5 | 122.0 | 14.8 | 22.9 | 21.8 |
| Human Activity | 14 | 5.4 | 92.3 | 13.1 | 21.6 | 22.6 |

In the following subsections, bioavailable lead concentrations from stream sediment, grid corners and areas of human activity within the Iqaluit grid area are presented.

#### 4.3.5.1 Stream Sediment Samples

Twenty-five sediment samples were collected and bioavailable lead concentrations are shown in Table 4.5. The concentrations range from 4.4 to 56.4 ppm, and have a median of 9.4 ppm. The results of an F-test indicate that variance of lead concentrations in stream sediment is not similar to variance of concentrations from background samples ($F = 3.256$;

P = 0.005). A t-test, assuming unequal variance, rejects the null hypothesis (t = -4.091; P < 0.001). Therefore, bioavailable lead concentrations of stream sediment in the grid area are significantly greater than background.

Sediment samples were collected from two streams (North 40 Creek and the Lake Geraldine Outflow) and from minor runoff ditches. Table 4.6 displays bioavailable lead concentrations.

Table 4.6 Bioavailable Lead Concentrations (ppm): Stream Sediment within Iqaluit Grid

| Description | Number of Samples | Minimum | Maximum | Median | Mean | Standard Deviation |
|---|---|---|---|---|---|---|
| North 40 Creek | 13 | 4.4 | 26.5 | 6.9 | 9.9 | 6.9 |
| Lake Geraldine | 9 | 6.3 | 56.5 | 25.9 | 28.0 | 19.5 |
| Runoff | 3 | 22.6 | 50.4 | 27.9 | 33.6 | 14.8 |

Thirteen samples were analyzed from North 40 Creek and runoff draining into the stream. Bioavailable lead concentrations are summarized in Table 4.6, and range from 4.4 to 26.5 ppm. The sample sites are shown on Figure 3.3 and individual concentrations are presented in Table 4.7.

Figure 4.3 displays bioavailable lead concentrations of sediment from North 40 Creek compared with background stream sediment concentrations. The results of an F-test fail to reveal a significant difference in variance of the North 40 Creek sediment and background sediment, at the 95 % confidence level (F = 1.362; P = 0.298). However, the results of a t-test, assuming equal variance, reject the null hypothesis and indicate that bioavailable lead concentrations in the sediment of North 40 Creek are significantly greater than background concentrations (t = -1.832; P = 0.039).

Table 4.7 Bioavailable Lead Concentrations (ppm): North 40 Creek

| Sample Site | Concentration | Sample Site | Concentration |
|---|---|---|---|
| N1 | 6.8 | N4 | 5.3 |
| N2 | 6.9 | N5 | 4.4 |
| N3A* | 21.8 | N6 | 6.9 |
| N3 | 14.0 | N7 | 8.3 |
| N4A* | 26.5 | N8 | 5.9 |
| N4B* | 7.9 | N9 | 7.7 |
| N4C* | 6.2 | (* indicates runoff into stream) | |

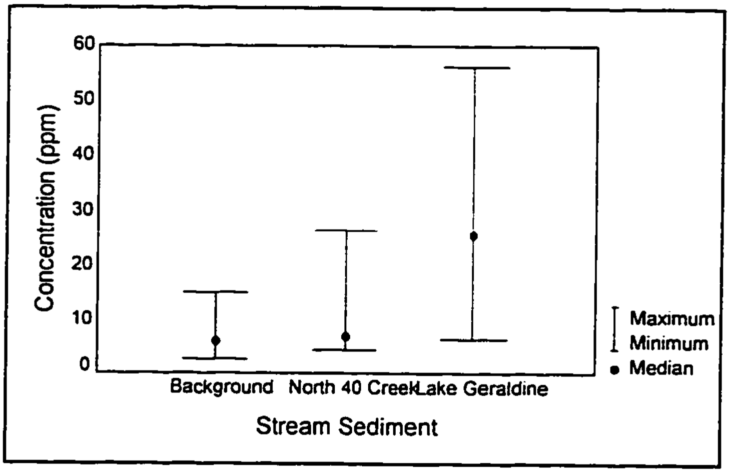


Figure 4.3 Bioavailable Lead Concentrations of Stream Sediment: Background, North 40 Creek and Lake Geraldine Outflow

Nine sediment samples were analyzed from the Lake Geraldine Outflow and a small runoff stream draining into it. Bioavailable lead concentrations, summarized in Table 4.6, range from 6.3 to 56.5 ppm, and have a median of 25.9 ppm. The sample sites are shown on Figure 3.4 and individual lead concentrations are displayed in Table 4.8.

Table 4.8 Bioavailable Lead Concentrations (ppm): Lake Geraldine Outflow

| Sample Site | Concentration | Sample Site | Concentration |
|---|---|---|---|
| LG1 | 47.0 | LG5B* | 9.4 |
| LG2 | 56.5 | LG5 | 6.7 |
| LG3 | 51.2 | LG6 | 25.9 |
| LG4 | 28.4 | LG7 | 20.9 |
| LG5A* | 6.3 | (* indicates runoff into stream) | |

Figure 4.3 displays bioavailable lead concentrations of sediment from the Lake Geraldine Outflow compared with background stream sediment. The results of an F-test fail to indicate a difference in the variance of the Lake Geraldine Outflow sediment and background sediment lead concentrations, at the 95 % confidence level ($F = 3.508$; $P = 0.330$). A t-test, assuming unequal variance, rejects the null hypothesis ($t = -4.048$; $P = 0.001$). Therefore, bioavailable lead concentrations in the sediment at the Lake Geraldine Outflow are greater than background concentrations.

4.3.5.2 Grid Corners

Sixty-two samples collected at grid corners were analyzed for bioavailable lead concentrations. Table 4.5 summarizes the concentrations, which range from 3.5 to 122.0 ppm with a median of 14.8 ppm. Table 4.9 presents the concentrations of each grid corner and Figure 3.2 shows the locations.

Figure 4.4 graphically compares bioavailable lead concentrations of the Iqaluit grid corners with background concentrations. An F-test concludes that the variances of the grid corners in Iqaluit and background sample subgroups are not similar, and, therefore, the two groups are significantly different (F = 3.400; P < 0.001). A t-test, assuming unequal variance, rejects the null hypothesis (t = -7.742; P < 0.001). The grid corners, as a sample subgroup, have significantly higher bioavailable lead concentrations than the background group.

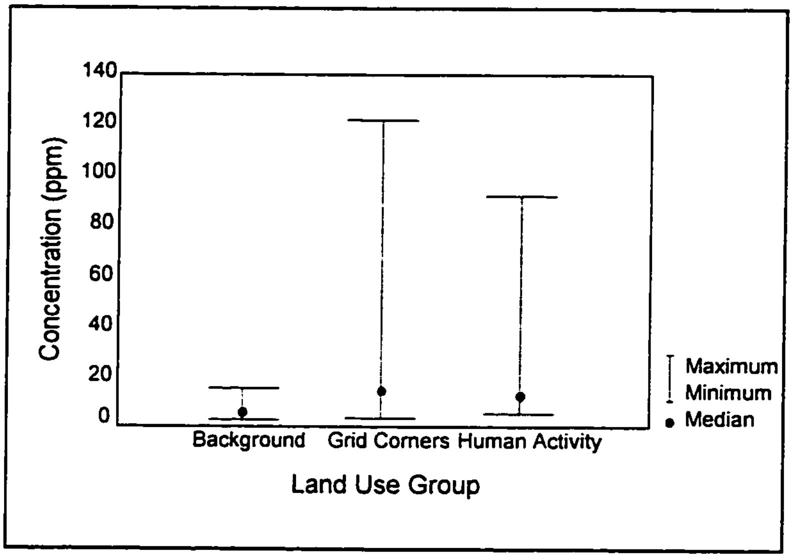


Figure 4.4 Bioavailable Lead Concentrations: Background, Iqaluit Grid Corners, and Human Activity

Table 4.9 Bioavailable Lead Concentrations (ppm): Iqaluit Grid Corners

| Sample Site | Concentration | Sample Site | Concentration | Sample Site | Concentration |
|---|---|---|---|---|---|
| A1 | 6.3 | C4 | 42.3 | D10 | 7.9 |
| A3 | 10.0 | C5 | 14.1 | D11 | 12.9 |
| A5 | 3.5 | C6 | 13.1 | D13 | 5.1 |
| A7 | 4.3 | C7 | 11.0 | D15 | 6.0 |
| A9 | 27.3 | C8 | 22.1 | D17 | 9.2 |
| B0 | 24.0 | C9 | 16.6 | E2 | 9.1 |
| B1 | 34.2 | C10 | 18.1 | E3 | 40.4 |
| B2 | 52.3 | C11 | 4.3 | E4 | 21.1 |
| B3 | 47.7 | C13 | 12.1 | E5 | 122.0 |
| B4 | 11.5 | C15 | 29.9 | E6 | 16.0 |
| B5 | 16.3 | C17 | 12.7 | E7 | 40.9 |
| B6 | 34.3 | D0 | 41.9 | E8 | 15.5 |
| B7 | 7.6 | D1 | 24.9 | E9 | 60.3 |
| B8 | 9.3 | D2 | 33.1 | E10 | 16.0 |
| B9 | 8.9 | D3 | 12.0 | E11 | 5.0 |
| B10 | 9.0 | D4 | 34.8 | F1 | 12.3 |
| B11 | 11.1 | D5 | 43.2 | F2 | 67.0 |
| C0 | 11.6 | D6 | 22.7 | F3 | 10.4 |
| C1 | 9.7 | D7 | 18.3 | F4 | 97.2 |
| C2 | 4.3 | D8 | 9.0 | F10 | 31.8 |
| C3 | 23.7 | D9 | 8.6 | Median | 14.8 |

* Note: Grid corners C13, C15, C17, D13, D15 and D17 are not shown on the map. These samples are part of the new Tundra Valley subdivision, which at the time of writing the thesis, had not yet been mapped by the town.

4.3.5.3 Areas of Human Activity

Specific areas of human activity were targeted for sampling, and include playgrounds, roads, culverts and a beach. Table 4.5 summarizes bioavailable lead concentrations of the human activity areas, which range from 5.4 to 92.3 ppm.

Figure 4.4 compares bioavailable lead concentrations from human activity areas with background concentrations. An F-test indicates that the samples within areas of human activity do not have similar variance to the background samples ($F = 3.175$; $P = 0.014$). A t-test, assuming unequal variance, rejects the null hypothesis ($t = -4.165$; $P < 0.001$). The samples within areas of human activities have significantly higher lead concentrations than background. The distribution of lead concentrations among various human activities is shown in Table 4.10.

Table 4.10 Bioavailable Lead Concentrations (ppm): Human Activities within Iqaluit Grid

| Description | Number of Samples | Minimum | Maximum | Median | Mean | Standard Deviation |
|---|---|---|---|---|---|---|
| Playgrounds | 9 | 5.4 | 92.3 | 23.3 | 28.5 | 26.1 |
| Roads | 2 | 6.3 | 9 | - | 7.7 | 1.9 |
| Culvert | 2 | 8.4 | 13.4 | - | 10.9 | 3.5 |
| Beach | 1 | 9.5 | - | - | - | - |

Playgrounds are an important land use group with respect to children's activities. Nine playgrounds within the grid of Iqaluit were sampled. Table 4.10 summarizes bioavailable lead concentrations of the playgrounds, which range from 5.4 to 92.3 ppm, and have a median of 23.3 ppm. Figure 3.2 shows the playground locations and Table 4.11 displays the bioavailable lead concentrations for each playground.

Table 4.11 Bioavailable Lead Concentrations (ppm): Playgrounds

| Sample Site | Playground Name | Concentration |
|---|---|---|
| Play1 | Joamie School | 12.8 |
| Play2 | Happy Valley | 40.7 |
| Play3 | Ikaluit | 11.2 |
| Play4 | Astro Hill | 24.3 |
| Play5A | Baseball Diamond | 23.3 |
| Play5B | Nakasuk School | 18.1 |
| Play6 | Inuksuk Highschool | 92.3 |
| Play7 | Lower Base | 28.3 |
| Play8 | Tundra Valley | 5.4 |

* Note: Play8 is located in the new Tundra Valley subdivision and therefore is not shown on the map.

Figure 4.5 displays bioavailable lead concentrations of the background and playground land use groups. An F-test reveals that the variances of the playground and background sample groups are not similar ($F = 3.449$; $P = 0.035$). A t-test, assuming unequal variance, rejects the null hypothesis ($t = -4.359$; $P = 0.001$), and reveals that bioavailable lead concentrations at the playgrounds are significantly higher than background.

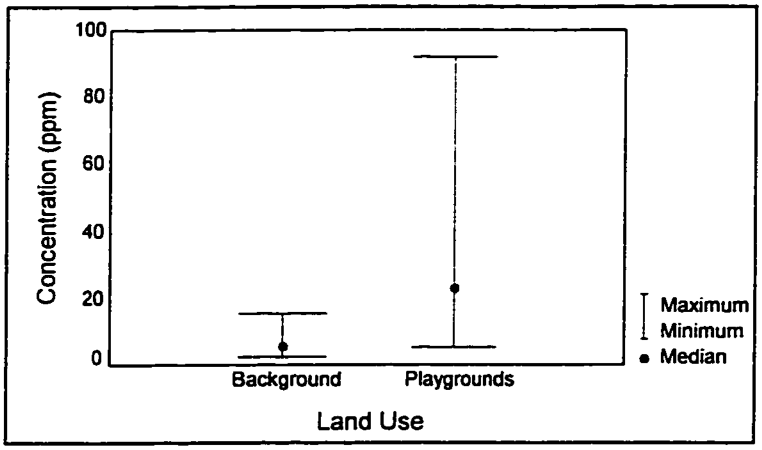


Figure 4.5 Bioavailable Lead Concentrations: Background and Iqaluit Playgrounds

4.3.5.4 Spatial Pattern within Grid Area

Given the number of sample sites within the grid area, it is possible to further investigate the spatial pattern of lead concentrations using the software package, SURFER. Bioavailable lead concentrations determined at the grid corners and playgrounds were kriged and isolines of equal lead concentration were created (Figure 4.6). Bioavailable lead concentrations less than 10.0 ppm approximate natural background levels. Areas with concentrations less than 30.0 ppm represent lead concentrations less than or equal to mean concentrations of the grid corners and playgrounds. Areas with concentrations between 30.0 and 120.0 ppm represent areas with bioavailable lead concentrations greater than the mean. The computer generated isolines clearly show areas with higher concentrations around the following: F2 grid corner; E9 grid corner; Play 6, Inuksuk Highschool; and E5 and F4 grid corners, an area known as the Lower Base. Play 6, F2 and E9 represent single sites with high concentrations. Lead concentrations at sites surrounding each of these points are below the

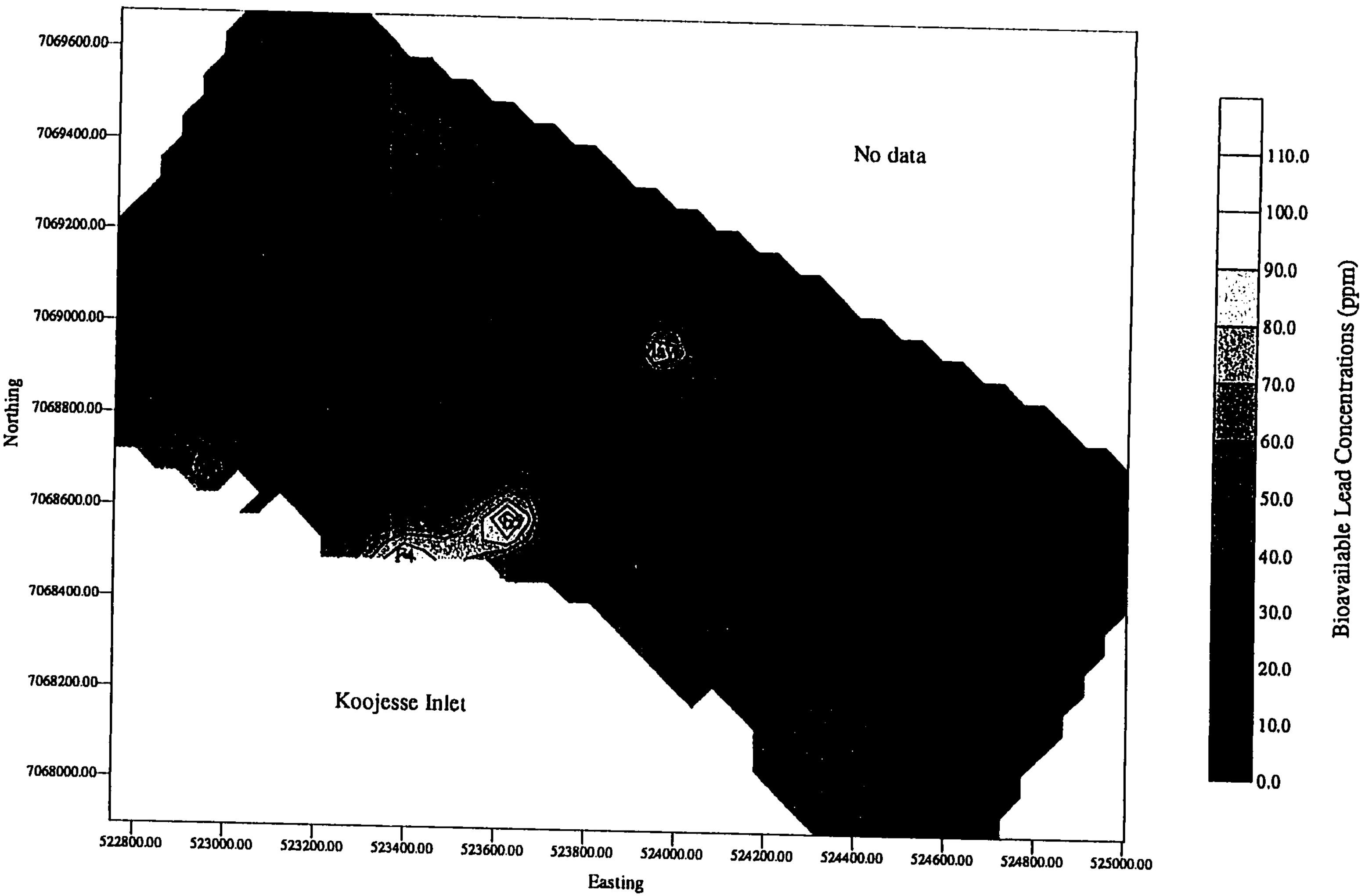


Figure 4.6 Isoline Map of Bioavailable Lead Concentrations in the Iqaluit Grid Area

mean. However, the Lower Base area has more than one high bioavailable lead concentration and a clustering of higher concentrations at some locations (E5, F4, D5) is evident.

### 4.3.6 Apex

Apex was overlaid with a grid, approximately 200 by 200 m. Six samples were collected from the grid corners and one from a playground at Nanook School. Bioavailable lead concentrations from Apex are summarized in Table 4.3, and range from 6.7 to 401.8 ppm, with a median of 29.9 ppm. Figure 3.5 shows the locations of the sample sites and Table 4.12 shows the concentrations.

Table 4.12 Bioavailable Lead Concentrations (ppm): Apex

| Sample Site | Concentration | Sample Site | Concentration |
|---|---|---|---|
| X1 | 88.4 | X5 | 29.9 |
| X2 | 6.7 | X6 | 12.9 |
| X3 | 401.8 | Play9 Nanook School | 19.0 |
| X4 | 96.6 | | |

Figure 4.7 compares bioavailable lead concentrations from Apex with the background samples. The results of an F-test indicate that the variance of the Apex and background land use groups are not similar (F = 11.743; P = 0.006). Therefore the two land use groups are significantly different. A t-test, assuming unequal variance, rejects the null hypothesis (t =

-3.670; P = 0.005). Bioavailable lead concentrations in the Apex grid area are significantly higher than background.

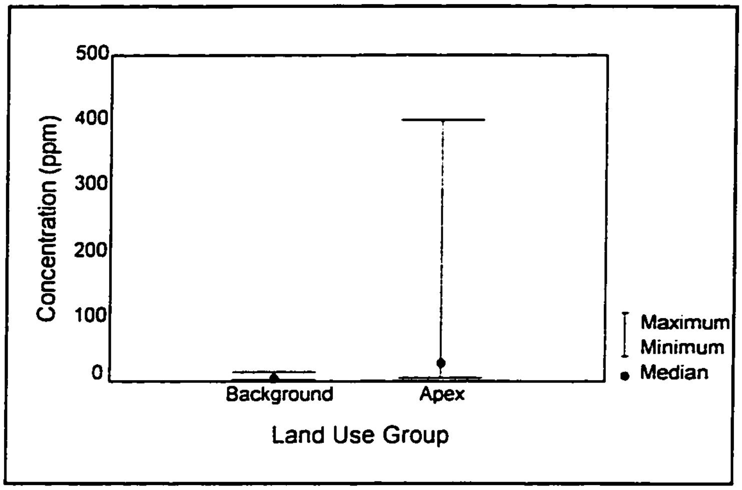


Figure 4.7 Bioavailable Lead Concentrations:
Background and Apex Grid Corners

## 4.4 TOTAL LEAD

The previous section showed that bioavailable lead concentrations in soil and sediment in the study area are above background levels. In this section, total lead concentrations are presented and are based on composite and individual samples. The composite samples are used to provide an average total lead concentration for an area. Total lead concentrations are compared to NWT and OMEE environmental guidelines and with concentrations reported in the literature.

4.4.1 Background

From the thirty-eight background samples, four individual samples were randomly chosen for total lead analysis. Total lead concentrations range from 29 to 34 ppm and have a mean of 31 ppm (Table 4.13). Three composites from the background group, which represent an average value, were made. Total lead concentrations of the composites range between 23 and 28 ppm (Table 4.13). Therefore, it can be assumed that background total lead concentrations in the Iqaluit area are less than 34 ppm.

Table 4.13 Total Lead Concentrations (ppm): Based on Sample Subgroup

| Sample Subgroup | Individual Samples | | | | | | Composite Samples |
|---|---|---|---|---|---|---|---|
| | Number of Samples | Minimum | Maximum | Median | Mean | Standard Deviation | |
| Background | 4 | 29 | 34 | 30 | 31 | 2 | 23 - 28 |
| Sylvia Grinnell Dump - West 40 | 3 | 101 | 1540 | 328 | 656 | 774 | - |
| Upper Base | 1 | 89 | - | - | - | - | 48 |
| Metal Dump North 40* | 2 | 44 | 48 | 46 | 46 | 3 | 78 |
| Iqaluit - Grid Area | 24 | 26 | 217 | 44 | 64 | 46 | 37 - 50 |
| Apex - Grid Area | 4 | 44 | 530 | 124 | 206 | 220 | - |

* Note: The composite sample is from the Metal Dump proper; the individual samples are from the runoff.

Table 4.14 compares the ranges of total lead concentrations found in this study with other data reported in the literature. In this study, individual and composite total lead concentrations in the background samples range from 23 to 34 ppm. According to the ESG (1995), mean total lead concentration of background samples was less than 5 ppm. However, the literature has suggested that lead concentrations can vary greatly. Background total lead concentrations in this research are comparable to Nriagu's (1978b) estimate of 10 to 37 ppm for average total lead concentrations.

4.4.2 Sylvia Grinnell Dump (West 40)

Three individual samples were chosen for total lead analysis from the Sylvia Grinnell Dump (West 40). Table 4.13 shows that total lead concentrations range from 101 to 1540 ppm. Total lead concentrations found at the Sylvia Grinnell Dump are the same order of magnitude as those found by the ESG (1995). The maximum total lead concentration reported in this study is 1540 ppm, compared with 1140 ppm found by the ESG (Table 4.14).

The Sylvia Grinnell Dump may be designated an industrial/commercial site. The maximum total lead concentration (1540 ppm) exceeds the NWT and OMEE recommended guidelines of 1000 ppm. This finding indicates the need for further investigation or remediation of the site because of the presence of lead levels above the level of concern for a child. However, the minimum (101 ppm) and median (328 ppm) total lead concentrations do not exceed the guidelines.

Because of its location within the Sylvia Grinnell territorial park, the Sylvia Grinnell Dump subsample group must also be compared to environmental guidelines for parkland

Table 4.14 Comparison of Total Lead Concentration (ppm)

| Sample Area | Concentration |
|---|---|
| Background (a) | 29 - 34 (individual); 23 - 28 (composite) |
| Background (b) | 5 (mean) |
| Background (c) | 10 - 37 |
| Sylvia Grinnell Dump - West 40 (a) | 101 - 1540 |
| Sylvia Grinnell Dump - West 40 (b) | < 10 - 1140 |
| Upper Base (a) | 89 (individual); 48 (composite) |
| Upper Base (b) | < 10 - 9680 |
| Metal Dump - North 40 (a) | 78 (composite) |
| Metal Dump - North 40 (b) | < 10 - 249 |
| Iqaluit Grid Area - Grid Corners and Playgrounds (a) | 26 - 217 |
| Apex Grid Area - Grid Corners and Playground (a) | 44 - 530 |
| Canadian Inner Cities (d) | 150 - 3000 |
| Soil-Lead Guidelines - Industrial/Commercial (e, f) | 1000 |
| Soil-Lead Guidelines - Residential/Parkland (e) | 500 |
| Soil-Lead Guidelines - Residential/Parkland (f) | 200 |
| Metal Dump Runoff - North 40 (a) | 44 - 48 |
| Iqaluit Grid Area - Stream Sediment (a) | 30 - 91 (individual); 37 - 50 (composite) |
| Arctic Coastal Stream Sediment (c) | 3.9 |
| Great Lakes sediment (g) | 0.3 - 1600 |
| Sediment Guidelines - Lowest Effect Level (h) | 31 |
| Sediment Guidelines - Severe Effect Level (h) | 250 |

a This study
b ESG (1995)
c Nriagu (1978b)
d OMEE (1994)
e NWT guidelines, from CCME (1991)
f Health-based guidelines, from OMEE (1993)
g Mudroch et al. (1988)
h Ontario provincial aquatic sediment guidelines, from Stone and Marsalek (1996)

sites. The NWT guideline for soil-lead at parkland sites is 500 ppm. The maximum total lead concentration exceeds the guideline but the minimum and median concentrations do not.

The OMEE recommends 200 ppm as the guideline for parkland sites. This level is lower than the level set by the CCME because it is based on exposure of a child aged six months to four years, who is especially vulnerable to lead from soil and its toxic effects. The maximum, median and mean total lead concentrations at the Sylvia Grinnell Dump exceed the OMEE recommendations, indicating that lead levels at the site are above the intake level of concern for a child. However, the minimum total lead concentration does not exceed the guideline.

### 4.4.3 Upper Base

One composite from the Upper Base was made of four samples and its total lead concentration is 48 ppm. One individual sample from the Upper Base was also tested for total lead and has a concentration of 89 ppm.

The ESG (1995) analyzed lead concentrations at the Upper Base to assess the need for site remediation. Table 4.14 displays total lead concentrations found by the ESG before site remediation. Total lead concentrations were much higher than background, with a maximum of 9680 ppm. The concentrations exceeded the ESG remediation criteria, and the site was cleaned up. Lead concentrations, in this study, were measured after the cleanup had begun and total lead concentrations (49 and 89 ppm) are much lower than pre-cleanup concentrations.

The Upper Base is a commercial/industrial site. Total lead concentrations of the

Upper Base, after cleanup, are much lower than the 1000 ppm guideline. According to the NWT environmental and OMEE recommended guidelines, the Upper Base does not require further remediation or pose a health risk to adults.

4.4.4 Metal Dump (North 40)

One composite sample was made from three samples collected directly in the Metal Dump (North 40). Total lead concentration, shown in Table 4.13, is 78 ppm and falls within the range of concentrations reported by the ESG (< 10 - 249 ppm). As an industrial/ commercial site, total lead concentrations at the Metal Dump are compared to the NWT and OMEE guidelines of 1000 ppm. Total lead concentration of the composite sample (78 ppm) is far below the guidelines. Therefore, the site does not require remediation or pose a health risk to adults.

Two sediment samples collected from ditches throughout the dump were analyzed for total lead concentration. Table 4.13 shows that the concentrations for the two samples are 44 and 48 ppm. Similar to bioavailable lead concentrations, total lead concentrations in the runoff from the dump are lower than those directly in the dump. Total lead concentrations in runoff sediment from the dump can be compared to the Ontario Provincial Sediment Quality guidelines. Total lead concentrations in the sediment of the dump runoff (44 and 48 ppm) exceed the lowest effect level but are below the severe effect level (Table 4.14).

4.4.5 Iqaluit Grid

Within the grid area of Iqaluit, twenty-four individual samples were chosen for total lead analysis and concentrations range between 26 and 217 ppm. The individual total lead concentrations from stream sediment, grid corners and playgrounds are summarized in Table 4.15.

Table 4.15 Total Lead Concentrations (ppm): Iqaluit Grid

| Description | Number of Samples | Minimum | Maximum | Median | Mean | Standard Deviation |
|---|---|---|---|---|---|---|
| Stream Sediment | 4 | 30 | 91 | 44 | 52 | 27 |
| Grid Corners | 11 | 26 | 217 | 43 | 69 | 55 |
| Playgrounds | 9 | 36 | 162 | 45 | 64 | 43 |

4.4.5.1 Stream Sediment

Four individual stream sediment samples (two each from North 40 Creek and Lake Geraldine Outflow) were randomly chosen for total lead analysis. The concentrations range between 30 and 91 ppm (Tables 4.14 and 4.15). These concentrations are higher than those reported by Nriagu (1978b) from other Arctic coastal streams (3.9 ppm mean). By comparison, total lead concentrations in this study area are much lower than concentrations reported in the Great Lakes (Mudroch et al., 1988).

The mean total lead concentration of two sediment samples from North 40 Creek is

35 ppm, and total lead concentration of the composite sample is 37 ppm. These concentrations exceed the Ontario provincial lowest effect level but are below the severe effect level. In the Lake Geraldine Outflow, the mean total lead concentration of two sediment samples is 69 ppm. Total lead concentration of the composite is 50 ppm. Therefore, total lead concentrations in the Lake Geraldine Outflow sediment also exceed the Ontario provincial lowest effect level but are below the severe effect level.

#### 4.4.5.2 Grid Corners

Eleven grid corners from Iqaluit's grid area were randomly chosen for total lead analysis. The concentrations are summarized in Table 4.15 and range from 26 to 217 ppm, with a mean of 69 ppm. Total lead concentrations in the Iqaluit built-up area are, on average, lower than concentrations found in other Canadian cities, which range between 150 and 3000 ppm (Table 4.14). However, the highest lead concentrations in Iqaluit are within the lower range of other Canadian cities.

The Iqaluit grid area is predominantly residential and subject to the 500 ppm limit set by the NWT guidelines. The maximum total lead concentration of grid corners within Iqaluit (217 ppm) is below the guidelines and, according to the NWT guidelines, the grid corners in Iqaluit do not require remediation.

The built-up area of Iqaluit can also be compared with the OMEE recommended guideline of 200 ppm for residential sites. The mean total lead concentration of grid corners in Iqaluit is 69 ppm. On average, the total lead concentrations of the grid corners in Iqaluit are under the soil guidelines. However, the maximum total lead concentration (E5 = 217 ppm) exceeds the 200 ppm guideline. A child at this site would be exposed to lead concentrations above the intake level of concern.

#### 4.4.5.3 Playgrounds

All nine playgrounds within the Iqaluit grid area were analyzed for total lead concentration. Lead concentrations for this land use range from 36 to 162 ppm and have a median of 45 ppm (Table 4.15). According to the NWT guidelines, playgrounds are considered residential/parkland areas and have a 500 ppm lead limit. All nine playgrounds are below the NWT guideline and do not require remediation.

Unlike the NWT guidelines, the OMEE gives special consideration to play areas and states that consideration should be given to ensuring that lead levels in covering soil used for play areas are limited to the greatest extent possible. For special situations such as these, the OMEE recommends soil quality consistent with background soil wherever possible. In order for Iqaluit's playgrounds to have soil quality consistent with background soil, they must have total lead concentrations of 34 ppm or less. However, the mean total lead concentration for the playgrounds in Iqaluit is 64 ppm. In fact, all of the playgrounds have total lead concentrations greater than background. Therefore, the lead concentrations of the playgrounds exceed the OMEE recommended guidelines.

### 4.4.6 Apex

Within Apex, four samples were analyzed for total lead and the concentrations are summarized in Table 4.16. Total lead concentrations are within the low end of the range of concentrations found in Canadian inner cities (Table 4.14).

Table 4.16 Total Lead Concentrations (ppm): Apex Grid Corners and Playground

| Description | Number of Samples | Minimum | Maximum | Median | Mean | Standard Deviation |
|---|---|---|---|---|---|---|
| Grid Corners | 3 | 113 | 530 | 135 | 259 | 235 |
| Playground | 1 | 44 | - | - | - | - |

As a residential area, the Apex grid corners are subject to the NWT guideline of 500 ppm. The maximum total lead concentration is 530 ppm (at X3), exceeding the NWT environmental guideline. However, the mean total lead concentration is 260 ppm, and below the lead guideline. Therefore, according to the NWT guidelines, Apex, as a whole, does not require remediation.

The OMEE recommends a 200 ppm lead limit for residential areas. The maximum total lead concentration (530 ppm) exceeds the recommended limits. This suggests that the lead level at site X3 is high enough to cause a child's lead intake to exceed the recommended level. However, the other grid corners in Apex are below the OMEE recommended guidelines. The playground in Apex has a total lead concentration of 44 ppm. This concentration is higher than background levels, recommended by the OMEE for children's play areas.

## 4.5 RELATIONSHIP BETWEEN TOTAL AND BIOAVAILABLE LEAD

Samples with both total and bioavailable lead data are examined in this section. To be consistent with total lead concentrations, bioavailable lead is rounded to the nearest whole number. Using Pearson's correlation analysis, a very strong relationship between bioavailable and total lead concentrations is found (Pearson's correlation = 0.937; $P < 0.001$). The regression analysis model in Figure 4.8 ($r^2$ = 0.877) shows that bioavailable lead concentrations increase with increasing total lead concentrations.

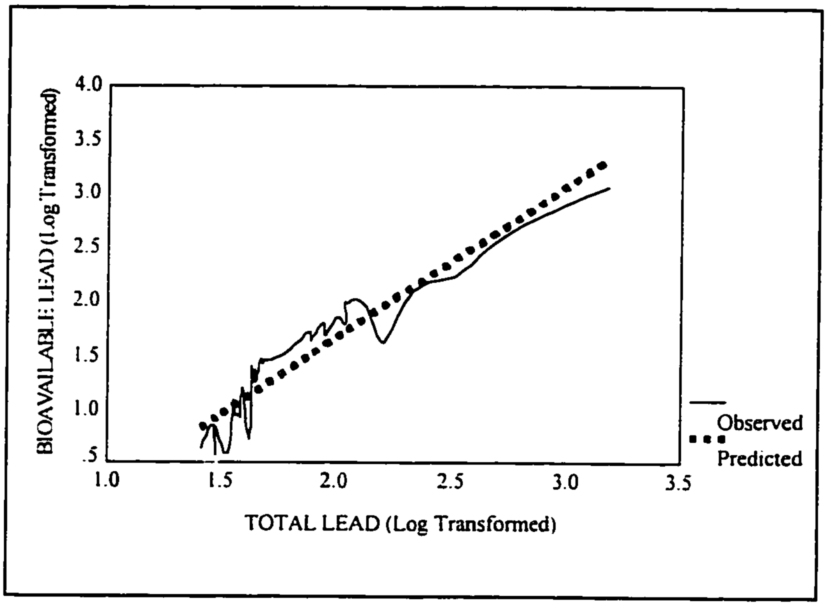


Figure 4.8 Total and Bioavailable Lead Concentrations (ppm): Regression Model

To further examine both total and bioavailable lead, the percentage of total lead which is bioavailable is calculated. Table 4.17 displays the bioavailable and total lead concentrations for samples, organized into subgroups. Pearson's correlation analysis, using all samples with both measurements, reveals a clear positive relationship between total lead concentrations and percentage which is bioavailable (Pearson's correlation = 0.673; $P < 0.001$). This is consistent with Chaney et al.'s (1989) finding that relative bioavailability increases with increased total lead concentration.

### 4.5.1 Background

Approximately 12 to 24 % of total lead is bioavailable for the background sample group (Table 4.17). Based on these four data points, the mean percentage of total lead which is bioavailable is 17 %.

### 4.5.2 Sylvia Grinnell Dump (West 40), Upper Base and Metal Dump (North 40)

In the Sylvia Grinnell Dump, 52 to 77 % of total lead is bioavailable. Based on the mean of three samples, 66 % of total lead is bioavailable. The proportion of bioavailable lead is greater at the Sylvia Grinnell Dump than in background samples. At the Upper Base, 70 % of total lead is bioavailable. Because only one sample in the Upper Base subgroup has values for both total and bioavailable lead, the mean percentage of total which is bioavailable cannot be calculated. In two sediment samples from the Metal Dump runoff, the percentage of total lead which is bioavailable is 56 and 43 %. Based on these two samples, 50 % of total lead is bioavailable within the Metal Dump. The fraction of total lead which is bioavailable is much higher at the Upper Base and Metal Dump than in the background samples.

Table 4.17 Bioavailable and Total Lead Concentrations (ppm): Based on Land Use Group

| Sample Subgroup | Sample Number | Bioavailable Lead Concentration (A) | Total Lead Concentration (B) | Percent (A/B) |
|---|---|---|---|---|
| Background | 17 | 7 | 29 | 24 |
| Background | 18 | 4 | 34 | 12 |
| Background | 27 | 5 | 30 | 17 |
| Background | 37 | 4 | 30 | 13 |
| MEAN (Background) | | | | 17 |
| Sylvia Grinnell Dump - West 40 | SM1 | 1185 | 1540 | 77 |
| Sylvia Grinnell Dump - West 40 | SM2 | 70 | 101 | 69 |
| Sylvia Grinnell Dump - West 40 | SM9 | 171 | 328 | 52 |
| MEAN (Sylvia Grinnell Dump - West 40) | | | | 66 |
| Metal Dump - North 40 | MDR3 | 27 | 48 | 56 |
| Metal Dump - North 40 | MDR4 | 19 | 44 | 43 |
| MEAN (Metal Dump - North 40) | | | | 50 |
| Upper Base | UB1 | 62 | 89 | 70 |

### 4.5.3 Iqaluit Grid

Bioavailable and total lead concentrations for sediment samples in North 40 Creek and the Lake Geraldine Outflow are shown in Table 4.18. At North 40 Creek, the mean percentage of total lead which is bioavailable is 29 %, and 56 % of total lead at Lake Geraldine Outflow is bioavailable. The proportion of total lead which is bioavailable is higher in the stream sediment, particularly from the Lake Geraldine Outflow, than in the background samples.

Table 4.18 Bioavailable and Total Lead Concentrations (ppm): Iqaluit Stream Sediment

| Sample Number | Bioavailable Lead Concentration (A) | Total Lead Concentration (B) | Percent (A/B) |
|---|---|---|---|
| N3 | 14 | 40 | 35 |
| N6 | 7 | 30 | 23 |
| MEAN | | | 29 |
| LG1 | 47 | 91 | 52 |
| LG4 | 28 | 47 | 60 |
| MEAN | | | 56 |

Table 4.19 displays both the total and bioavailable lead concentrations of grid corners. The percentage of total lead which is bioavailable ranges from 13 to 68 %. Based on the mean of these eleven samples, 37 % of total lead is bioavailable. The proportion of total lead which is bioavailable is higher at the grid corners than in the background samples.

Table 4.19 also displays the bioavailable and total lead concentrations for the nine playgrounds in the Iqaluit grid area. The percentage of total lead which is bioavailable ranges from 12 to 84 %. Based on the mean value of these nine playgrounds, 43 % of total lead is bioavailable. The proportion of total lead which is bioavailable at the playgrounds is greater than the portion in the background samples.

Table 4.19 Bioavailable and Total Lead Concentrations (ppm): Grid Corners and Playgrounds

| Sample Site | Bioavailable Lead Concentration (A) | Total Lead Concentration (B) | Percent (A/B) |
|---|---|---|---|
| B2 | 52 | 77 | 68 |
| B9 | 9 | 38 | 24 |
| C2 | 4 | 30 | 13 |
| C11 | 4 | 26 | 15 |
| D5 | 43 | 78 | 55 |
| D9 | 9 | 39 | 23 |
| E2 | 9 | 37 | 24 |
| E5 | 122 | 217 | 56 |
| E9 | 60 | 110 | 55 |
| F3 | 10 | 43 | 23 |
| F10 | 32 | 59 | 54 |
| MEAN | | | 37 |
| Play1 | 13 | 39 | 33 |
| Play2 | 41 | 162 | 25 |
| Play3 | 11 | 36 | 31 |
| Play4 | 24 | 43 | 56 |
| Play5A | 23 | 45 | 53 |
| Play5B | 18 | 45 | 40 |
| Play6 | 92 | 110 | 84 |
| Play7 | 28 | 50 | 56 |
| Play8 | 5 | 42 | 12 |
| MEAN | | | 43 |

4.3.4 Apex

Table 4.20 displays both bioavailable and total lead concentrations for samples in Apex. The percentage of total lead which is bioavailable ranges from 43 to 86 %. Based on these four samples, 68 % of total lead is bioavailable in Apex, which is a greater proportion than in the background group. The bioavailable percentage at the playground in Apex (43 %) is the same as the mean percentage for the playgrounds in Iqaluit.

Table 4.20 Bioavailable and Total Lead Concentrations (ppm): Apex

| Sample Site | Bioavailable Lead Concentration (A) | Total Lead Concentration (B) | Percent (A/B) |
|---|---|---|---|
| X1 | 88 | 135 | 65 |
| X3 | 402 | 530 | 76 |
| X4 | 97 | 113 | 86 |
| Play9 | 19 | 44 | 43 |
| MEAN | | | 68 |

4.6 CONCENTRATIONS AT DEPTH

Twenty sub-surface samples were analyzed for bioavailable lead concentration, and the data are presented in Table 4.21. Depending on surface hardness, the depth of the sub-surface samples ranges from to 5 to 20 cm. Elevated lead concentrations in soils deeper than 20 cm is unlikely because of lead's limited mobility and because of permafrost, which restricts downward leaching.

Table 4.21 Bioavailable Lead Concentrations (ppm): Surface and Depth

| Sample Subgroup | Surface Concentration | Depth Concentration | Depth (cm) |
|---|---|---|---|
| Background | 5.3 | 5.1 | 20 |
| Background | 4.9 | 4.3 | 20 |
| Metal Dump - North 40 | 23.1 | 18.3 | 10 |
| Metal Dump - North 40 | 14.6 | 24.1 | 10 |
| Metal Dump - North 40 | 60.0 | 28.8 | 10 |
| Iqaluit - Stream Sediment (N6) | 6.9 | 7.5 | 10 |
| Iqaluit - Grid Corner (B1) | 34.2 | 22.5 | 20 |
| Iqaluit - Grid Corner (B6) | 34.3 | 29.2 | 5 |
| Iqaluit - Grid Corner (B10) | 11.1 | 4.3 | 20 |
| Iqaluit - Grid Corner (C10) | 18.1 | 20.7 | 10 |
| Iqaluit - Grid Corner (E2) | 9.1 | 23.3 | 20 |
| Iqaluit - Grid Corner (F1) | 12.3 | 46.1 | 20 |
| Iqaluit - Grid Corner (F2) | 67.0 | 108.6 | 20 |
| Iqaluit - Playground (Play1) | 12.8 | 20.0 | 10 |
| Iqaluit - Playground (Play2) | 40.7 | 43.9 | 10 |
| Iqaluit - Playground (Play3) | 11.2 | 47.3 | 10 |
| Iqaluit - Playground (Play4) | 24.3 | 45.0 | 10 |
| Iqaluit - Playground (Play5A) | 23.3 | 32.5 | 10 |
| Iqaluit - Playground (Play7) | 28.3 | 21.2 | 10 |
| Apex - Grid Corner (X5) | 29.9 | 50.3 | 10 |
| MEAN | 23.6 | 30.2 | |

Eight of the twenty sample sites have elevated lead at the surface compared to depth. Both background samples, for example, have concentrations slightly greater at the surface than at depth. Twelve sites have greater concentrations at depth. This may be the result of downward migration of lead, or due to physical disturbance of the ground, such as road grading or excavation, whereby surface layers are disturbed.

## 4.7 GRAIN SIZE ANALYSIS

Grain size analysis was performed on four samples to determine the proportion of sample less than 63 μm. Table 4.22 shows that between 0.8 to 10.1 % of each of the four samples is less than 63 μm. Materials from the tundra, stream, and playground are predominantly sand, and road materials are coarser than sand.

Table 4.22 Grain Size

| Sample Description | Silt and Clay | Very Fine and Fine Sand | Medium Sand | Very Coarse and Coarse Sand | Granule | Pebbles, Cobbles, Boulders |
|---|---|---|---|---|---|---|
| | < 63 μm | 63 μm - 0.125 mm | 0.25 - 0.50 mm | 0.50 - 1.68 mm | 1.68 - 4.0 mm | > 4 mm |
| Tundra | 10.1 | 29.9 | 16.9 | 16.3 | 3.1 | 23.7 |
| Stream Sediment | 27.2 | 49.1 | 17.2 | 5.5 | 1.0 | 0 |
| Road | 0.8 | 9.5 | 14.5 | 27.7 | 19.0 | 28.5 |
| Playground | 1.9 | 25.0 | 27.7 | 23.7 | 14.0 | 7.7 |

# CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS

## 5.1 SUMMARY OF FINDINGS

The results of this research show that elevated levels of lead (ie. above natural background levels) are present in the study area. Concentrations of bioavailable lead (operationally-defined as 0.5 N HCl extractable) in background samples are 6.9 ppm, on average. In this study, concentrations above background (10 ppm) are attributed to anthropogenic activities. The t-tests reveal that the bioavailable lead concentrations of all sample subgroups are significantly greater than background, at the 95 % confidence level.

The land use groups, or sample subgroups, have varying ranges of lead concentrations. The highest bioavailable lead concentrations, as well as the greatest range, are found at the Sylvia Grinnell Dump. Lead concentrations at this site range from 8.0 to 1185.3 ppm, and have a median of 189.3 ppm. The next highest concentrations are found in Apex, which range from 6.7 to 401.8 ppm. Mean and median bioavailable lead concentrations at the Upper Base, Metal Dump and Iqaluit grid area are similar. For example, mean concentrations of the three sample subgroups are 25.7, 21.2 and 21.8 ppm, respectively. However, the Iqaluit grid area has a greater range of concentrations than the other two land use groups because of a high maximum concentration at one of the grid corners.

Generally, total lead concentrations do not exceed Northwest Territory guidelines (adopted from the CCME). A guideline of 500 ppm is imposed for residential land uses, which include the Iqaluit and Apex grid areas. Only one sample site, X3 in Apex (see Figure

3.4), exceeds this guideline. The remaining residential areas are below the NWT guidelines for soil-lead concentrations. At the Sylvia Grinnell Dump (see Figure 3.1), the NWT industrial/commercial and parkland/residential guidelines of 1000 and 500 ppm, respectively, are exceeded at one sample site. Concentrations of lead above the guidelines indicate the need for further investigation or remediation of the sites. Total lead concentrations in stream sediment from North 40 Creek and Lake Geraldine Outflow exceed the Ontario provincial lowest effect level, but not the severe effect level, for aquatic sediment.

The guidelines recommended by the Ontario Ministry of Environment and Energy (OMEE) for commercial/industrial sites are the same as the NWT guidelines. Total lead concentration greater than 1000 ppm at the Sylvia Grinnell Dump suggests that lead concentrations at the site are potentially harmful to adults. The OMEE guidelines impose lower limits for residential and parkland sites (200 ppm) than the NWT guidelines. The following sites have total lead concentrations which exceed the OMEE recommended guidelines: two sites at the Sylvia Grinnell Dump; X3 in the Apex grid area; and E5 in the Iqaluit grid area (see Figure 3.2). This suggests that the lead concentrations at these sites contribute lead levels above the intake level of concern for a child. According to the OMEE's special consideration for playgrounds, lead concentrations in the playgrounds in Iqaluit and Apex are higher than recommended. The OMEE suggests that lead concentrations similar to background concentrations are desirable in these areas. All playgrounds within the study area have total lead concentrations which exceed the background range of 23 to 34 ppm.

On average, 17 % of total lead in the background samples is bioavailable. However, the mean percentage of lead which is bioavailable is higher in the other sample subgroups. For example, 70 % of total lead is bioavailable at the Upper Base, 68 % in Apex, 66 % at the Sylvia Grinnell Dump, 50 % at the Metal Dump, 43 % at the Iqaluit playgrounds and in stream sediment, and 37% at the Iqaluit grid corners.

Comparing data from this study with that reported in the literature reveals that the magnitude of lead contamination in Iqaluit is not as great as in some southern cities. Nevertheless, the town has some lead contamination. There is a widespread distribution of lead concentrations above background, but below environmental guidelines throughout the study area. This overall pattern is interspersed with isolated areas where concentrations approach or exceed environmental guidelines.

The highest concentrations of lead are found at a point source, the Sylvia Grinnell Dump, outside the built-up area of Iqaluit. The site, which is located inside a territorial park, was initially used by the US military to dump garbage, construction materials, vehicles and electrical equipment.

A clustering of elevated lead concentrations, although lower than those at the Sylvia Grinnell Dump, is found in the Lower Base area of town, where the US military first built homes. Within the Lower Base area, lead concentrations at grid corners E5, F4, and D5 exceed the average level. The Lower Base, located downslope from the Upper Base and Metal Dump, may receive runoff from these sites.

## 5.2 LINKS WITH HUMAN HEALTH

The results of this study have revealed elevated lead concentrations in soil and sediment in Iqaluit. Although human exposure to lead is possible via several different pathways, lead in soil and sediment are two main pathways. Once it has been established that lead concentrations above background levels are present in the study area, the potential link with human health must be evaluated.

Studies which have found links between human health problems and lead in soil have reported total lead concentrations of: 150 to 500 ppm (Chaney et al., 1989); 500 to 2000 ppm (Hertzman et al., 1991); and over 1000 ppm (OMOE, 1975; Fairey and Gray, 1970). The presence of such high concentrations of lead present an obvious risk to young children living in those areas. Upon reporting such lead concentrations, the studies were able to demonstrate correlations between lead in soil and human health problems, such as increased blood-lead levels and lead poisoning. The lead concentrations in Iqaluit, with the exception of a few sample sites, are not as high as the levels reported in other studies. Furthermore, the NWT guidelines and the health-based guidelines recommended by the OMEE suggest that the lead levels at most sites in the study area do not present a risk to human or ecosystem health. Therefore, a serious health hazard due to lead in soil and sediment is not apparent.

However, assigning risk based on research from larger, southern cities must be done with caution. It is perhaps a false assumption that environmental guidelines, health standards and risk levels are generalizable to the Arctic. Comparison of total lead concentrations in temperate and permafrost environments may not be appropriate. In addition, risk from soil-lead is controlled by many factors aside from total lead concentration. Bioavailability, for example, can influence the rate of lead absorption in the body.

Lead has a direct health impact only when it is in a biologically available state, and uptake is thus restricted to bioavailable lead (Campbell et al., 1988). As a result, a value for total lead is almost always an overestimate of the amount of lead that is available and that will be absorbed (Wixson and Davies, 1993). Studies which have reported links between environmental lead and human health have analyzed total lead concentrations, thereby overestimating the amount of lead which is available by assuming 100 % absorption. Bioavailable lead concentrations reported in this study are an estimate of the amount of lead which is potentially available and will be absorbed. As such, the values more directly reflect the risk to human health. However, bioavailable lead concentrations have not been investigated in the studies linking environmental lead to human health. In addition, environmental guidelines for bioavailable lead do not exist, making it difficult to quantitatively assess the link between bioavailable concentrations and human health at this point in time.

Many factors influence the uptake of lead and make establishing clear causal links difficult. The uncertainty of establishing links between environmental lead and human health, notwithstanding, some qualitative statements concerning potential links between lead in soil and sediment and human health in Iqaluit can be made.

In every sample subgroup, a proportion of the lead present is in a biologically available form. Furthermore, the proportion of lead in this form is higher in the residential areas than in background samples. In the residential area of Apex, where lead concentrations are elevated, more than half of the total lead is in a biologically available form. Lead bioavailability is strongly related to lead toxicity and harmful health effects result from humans absorbing excessive amounts of bioavailable lead. This research also shows that soil-lead is biologically available in areas where children play. In addition, activities normally encountered in play areas often result in increased soil ingestion, which increases the normal risk of exposure to lead (OMEE, 1993). In Iqaluit playgrounds, the combination of bioavailable lead and physical activities further enhance exposure.

Sample areas, such as residential areas, playgrounds and roads, have lead concentrations above background and have predominantly bare surfaces with very little ground cover. Exposure to lead is enhanced if children live in homes or play in areas with higher percentages of bare soil (Hilts, 1996). Indeed, most of Iqaluit and Apex are bare soil. This suggests that in the study area, the exposure of children to lead in soil is enhanced because they play on bare soil surfaces. Also, the town of Iqaluit experiences high winds, which can mobilize and transport fine-grained particles from the ground surface. Consequently, children often inhale lead-dust originating from these bare soil surfaces, which is harmful. The combination of bare surfaces and blowing dust make it very difficult to stay clean while outdoors. Research has suggested that wearing "dirty" clothes can affect a child's blood-lead levels (Wixson and Davies, 1993).

Field work for the thesis was undertaken in the summer, when children nearly always play outdoors. Children were observed playing in designated playgrounds, as well as roads and culverts, during all hours. Situated within a different cultural environment, children often play outside largely unsupervised. Chaney et al. (1989) state that a "poorly" supervised child may have increased lead exposure because behaviours, such as pica and mouthing dirty objects, would not be noticed.

In Iqaluit, environmental factors (elevated lead concentrations, bioavailable forms of lead, bare soil surfaces) and behavioural factors (vigorous play outside) combine to create a lead exposure risk. The children in Iqaluit have a reprieve from exposure to lead in soil in the winter, when the ground is frozen and partially or completely covered with snow. However, studies in temperate regions have shown that children's blood-lead levels are elevated in the summer, because of exposure to soil-lead (Schell et al., 1997).

In conclusion, Iqaluit has some lead contamination, although the magnitude is not as great as in some southern cities. The research findings reveal that elevated levels of bioavailable lead (ie. above average background concentrations of 10 ppm) are present in the study area. Concentrations above background are considered to be the result of anthropogenic activities. Total lead concentrations generally do not exceed environmental guidelines, except sites in the Sylvia Grinnell Dump, Apex and Lower Base area of town which exceed OMEE recommended guidelines derived from health-based criteria. The research concludes that there is not a serious health hazard posed by lead levels in the soil and sediment in the study area. However, several environmental and behavioural factors create a risk of lead exposure for children.

## 5.3 RECOMMENDATIONS:

Based on this study's findings, the following recommendations are presented:

1) As a preventative measure, unnecessary lead exposure should be reduced to a minimum.

- Following the NWT and CCME guidelines, remediation of the Sylvia Grinnell Dump is recommended. A cleanup of the site must include removal of debris and contaminated soil. Cleanup of the Sylvia Grinnell Dump was suggested by ESG (1995), but has not been initiated. The debris is unsightly and contaminated soil may pose a risk to children who contact it.

- Management should focus on abatement of lead-dust from contaminated soil. Residents regularly complain of dust from unpaved roads. Attempts to reduce dust by spraying water have been ineffective. Road paving is recommended to reduce the amount of dust in the air, thereby limiting exposure to lead-dust. Although paving roads has been previously suggested (UMA, 1996), most roads remain unpaved.
- Management should also focus on ground cover projects to reduce lead exposure. Ground cover such as grass, concrete, or shrubs can provide an effective barrier between contaminated soil and children and thereby limit the amount of lead-dust from contaminated soil. In Iqaluit, the reintroduction to the residential areas of tundra vegetation, such as mosses and sedges, is proposed.
- Community-based educational programs, which are culturally sensitive, should stress prevention and inform residents of the risks associated with exposure to lead in soil. The most exposed child is described as a poorly-supervised child who is regularly exposed to lead-rich soil, exhibits pica and has poor nutrition (Chaney et al., 1989). Research has also shown that children tend to have higher blood-lead levels if they chew their fingernails, put soil and dirty toys in their mouths, or live in a house where someone smokes (Hilts, 1996). Educational messages aimed at hygiene (ie. frequent hand washing) and personal habits (ie. preventing pica) have proven effective in reducing lead exposure in other studies (Hilts, 1996).

2) Future directions for this research should continue to focus on environmental and health factors.

- A more detailed study of portions of the study area with high lead concentrations (Apex and the Lower Base) is recommended. A finer grid system of 100 or 50 m should be used to sample these areas and further investigate the lead concentrations. In addition, continual monitoring of soil-lead levels in Apex and the Lower Base is essential.
- House dust, particularly in homes situated in areas with higher lead concentrations, should also be tested for lead. It is generally considered that soil and dust are strongly related and studies have found children suffering from lead poisoning had ingested large quantities of lead in dust. Given the amount of time spent indoors during the winter, children would be substantially exposed to house dust, which may be contaminated with lead from outdoor soils.
- Screening for lead in children is recommended, particularly in the Lower Base area and Apex. This screening would determine the extent and degree of current lead exposure and further assess the contribution of soil and sediment to the lead burden of children. Blood or hair samples could be tested. Hair sampling is a more convenient and non-invasive procedure and is well suited for large scale epidemiologic studies (Tuthill, 1996). Screening for lead in children should be conducted during both the winter and summer seasons. Testing children for lead twice a year would address whether seasonality plays a role.

3) Guidelines for lead in soil and sediment should be revised.

- Lead guidelines appropriate to an Arctic environment must be created. The NWT guidelines follow those set by the CCME, which were adopted from values used in various jurisdictions in Canada. The guidelines were not based on an Arctic ecosystem, which is particularly fragile and vulnerable to the effects of contaminants. In such an environment, cold temperatures and reduced ultraviolet radiation slow the degradation of contaminants, and permafrost produces impermeable conditions with respect to potential leaching and migration of substances through frozen layers. As a result, lead behaves differently in northern than in more temperate environments, and guidelines based on southern environments are not appropriate.
- Human health must be considered when establishing guidelines for lead in the environment. The health-based criteria defined by the OMEE should be used in setting guidelines which are appropriate to an Arctic environment. In addition, lead bioavailability should be considered when setting limits for lead in soil and sediment.
- Lead guidelines for children's play areas must be established. Children are more vulnerable than adults to the toxic effects of lead and, given the same concentration of lead, children's exposure will be higher. In addition, vigorous play may result in even higher soil ingestion. Therefore, areas such as playgrounds must have specific guidelines for soil-lead levels. Standards for a child playing in a northern environment could be adapted from the OMEE recommended guidelines.

## 5.4 CONCLUDING REMARKS

Like other study areas reviewed in the literature, Iqaluit has some lead contamination of its soil and sediment. However, further comparison of Iqaluit with southern cities is difficult given its very different environment. Lead concentrations in Iqaluit reflect the influences of permafrost and a relatively small population, a majority of whom are Inuit. By contrast, high lead concentrations reported in the literature are from more populated cities in temperate regions. For example, the high lead concentrations found in Riverdale, Toronto reflect heavy industry and vehicular traffic, and a large urban population. Similarly, lead concentrations in Trail, BC reflect heavy industry, but within a valley environment. Iqaluit's physical and human environments, in addition to its lead concentrations, are dissimilar from those investigated in previous research, making direct comparison unsuitable.

The magnitude of lead contamination in Iqaluit may be comparable to other Arctic communities, located within similar physical and human environments. However, limited research has been conducted in the Arctic. Eleven communities exist, including Lake Harbour where I have collected samples which need to be analyzed, where similar research could be undertaken. My research provides information about background lead concentrations in tundra environments for future spatial and temporal comparisons, with, for example, Lake Harbour. In addition to providing new information, it contributes to the existing literature. My research adds to the recognition that Arctic communities are not free from contamination due to anthropogenic activities.

Environmental and health guidelines suggest that the levels of lead in soil and sediment in Iqaluit do not pose a serious health hazard. However, these guidelines do not consider bioavailability, despite its relationship to toxicity and health, nor are they appropriate for Arctic environments. Just as the physical and human environments of Iqaluit and southern cities differ, so does human-lead exposure. After the long, dark Arctic winter, the commencement of summer coincides with excited outdoor activity. The many children in Iqaluit celebrate the season by playing during all hours of the day. Groups of children enjoy hours of unsupervised play outside. The result of such vigorous play is direct soil contact and soil-lead exposure greater than what might be observed in a southern city. During the summer, the amount of time children in Iqaluit spend playing outside, coming into contact with, and ingesting or inhaling lead-contaminated soil is great. This substantial exposure, combined with "poor" supervision, "dirty" clothes, bare soil surfaces and bioavailable forms of lead, put the children of Iqaluit substantially at risk from soil and sediment-associated lead. Indeed, the children of Iqaluit are at greater risk than many of the cross-cultural groups of children reported in the literature.

However, lead-related health problems are not limited to exposure from soil and sediment alone. Humans are exposed to lead via numerous pathways. In Iqaluit, humans may be exposed to low-levels of lead in the air and dust, water and diet. Although contamination of country-foods has been reported in the literature, no studies have been undertaken in the Iqaluit area. The potential uptake of lead by vegetation, including blueberries grown in the area, and by animals, including Arctic char from the Sylvia Grinnell River, need to be examined for their potential contribution to human-lead exposure. The cumulative effect of exposure via these different pathways may result in blood-lead levels above those considered safe. Although lead concentrations in soil and sediment are low, high degrees of exposure combined with exposure from other pathways may result in harmful health effects.

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IMAGE EVALUATION
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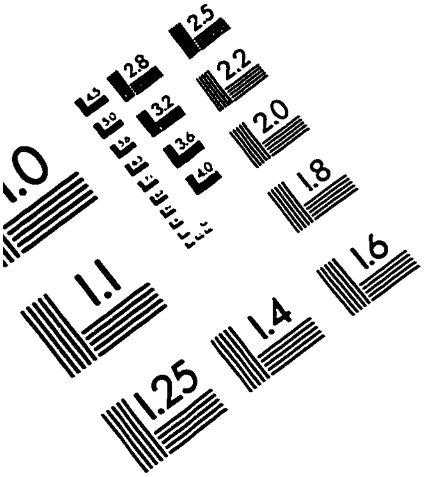

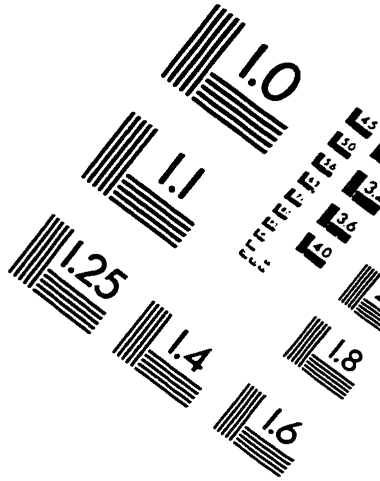

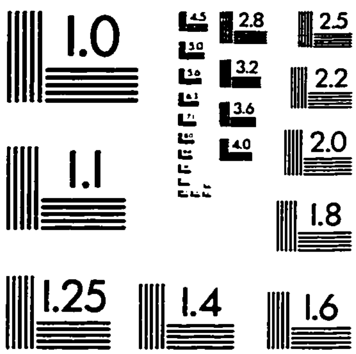


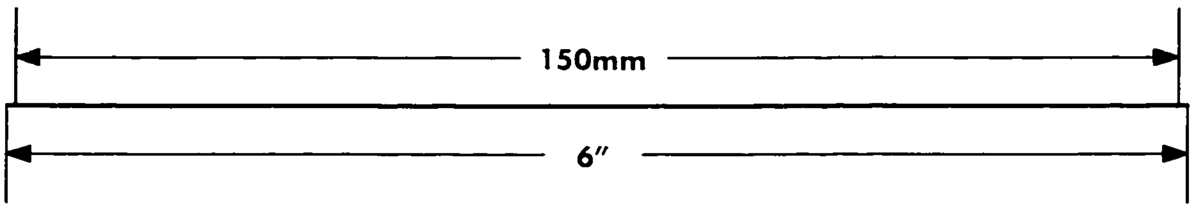


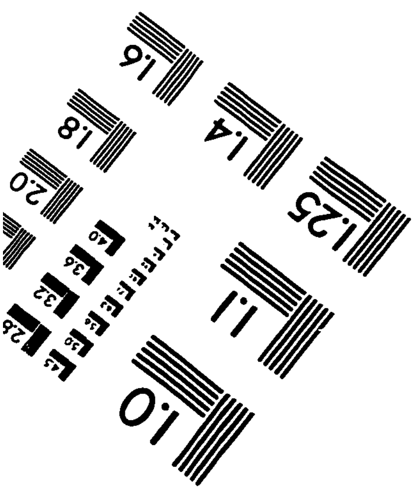

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1653 East Main Street
Rochester, NY 14609 USA
Phone: 716/482-0300
Fax: 716/288-5989