SCIENCE INTEGRITY KNOWLEDGE

ASSESSMENT OF ELEVATED CONCENTRATIONS OF LEAD IN SOIL IN WINNIPEG NEIGHBOURHOODS

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Manitoba Health, Seniors and Active Living

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LIST OF ACRONYMS

List of Acronyms	
AAQC	Ambient Air Quality Criterion
ABA	Absolute Bioavailability
ACLPP	Advisory Committee on Childhood Lead Poisoning Prevention
ADHD	Attention Deficit Hyperactivity Disorder
AECL	Atomic Energy of Canada Ltd
AFN	Assembly of First Nations
ALAD	Erythrocytic (Delta)-Aminolevulinic Acid Dehydratase
ALM	Adult Lead Model
BC CDC	British Columbia Centre For Disease Control
BC Environment	British Columbia Ministry of Environment and Climate Change Strategy
BHELS	Broken Hill Environmental Lead Study
BLLs	Blood Lead Levels
BMD	Benchmark Dose
CAC	Community Advisory Committee
CCME	Canadian Council of Ministers of The Environment
CDC	Centers for Disease Control and Prevention
CDTSC	California Department of Toxic Substances Control
CHMS	Canadian Health Measures Survey
CIHI	Canadian Institute for Health Information
CLPPP	Childhood Lead Poisoning Prevention Program
CLPPP	Southern Nevada Childhood Lead Poisoning and Prevention Program
CoA	Certificates of Approval
CSCE	Canadian Society for Chemical Engineering
CTEC	Butte Citizen Technical Environmental Committee
CWLEI	Cumulative Water Lead Exposure Index
DEFRA	United Kingdom Department of Environment Food and Rural Affairs
DHSS	Missouri Department of Health and Senior Services
DLHS	Dust-Level Hazard Standard
ECCC	Environment Canada and Climate Change
ECE	Manitoba Sustainable Development Environmental Compliance and Enforcement Branch
ECF	Extracellular Fluid
EDI	Early Development Instrument
EFSA	European Food Safety Agency
ESA	Environmental Site Assessment
FDA	Food and Drug Administration

List of Acronyms	
FEP	Free Erythrocyte Porphyrin
GSD	Geometric Standard Deviation
HBMS	Hudson Bay Mining and Smelting Co.
HEPA	High-Efficiency Particulate Air
HERO	Human and Ecological Risk Office
HI	Hazard Index
IEUBK	US EPA's Integrated Exposure, Uptake, And Biokinetic Model
INSPQ	Institute National De Santé Publique du Québec
IVIVC	*In Vivo-In Vitro* Correlation Tests
JECFA	Joint Expert Committee on Food Additives and Contaminants
MACT	Maximum Achievable Control Technology
MDEQ	Michigan Department of Environmental Quality
MDHHS	Michigan Department of Health and Human Services
MECP or OMECP	Ontario Ministry of The Environment, Conservation, And Parks
MIACC	Municipal Industrial Accidents Council of Canada
MRL	Minimal Risk Level
MSA	Multiple Source Analysis
MSD	Mass Fraction
NAAQS	National Ambient Air Quality Standards
NAPS	National Air Pollution Surveillance
NHANES	National Health and Nutritional Examination Survey
NHMRC	National Health and Medical Research Council
NHMRC	National Health and Medical Research Council
NTP	Us National Toxicology Program
OEHHA	California Office Of Health Hazard Assessment
PBET	Physiologically-Based Extraction Test
PBPK	Physiologically-Based Pharmacokinetic
$PM_{2.5}$	Fine Particulate Matter
PM_{10}	Coarse Particulate Matter
POD	Point of Departure
RBA	Relative Bioavailability
RBALP	Relative Bioaccessiblity Leaching Procedure
RCT	Randomized Control Trial
REB	Research Ethics Board
RSD	Relative Standard Deviation
SA Health	South Australia Health
SBRC	Solubility/Bioavailability Research Consortium

List of Acronyms	
SEM	Scanning Electron Microscopy
SQGs	Canadian Soil Quality Guidelines
SSL	Soil Screening Level
TAC	Technical Advisory Committee
TCLTF	Trail Community Lead Task Force
TDS	Total Dietary Study
the Province	Province of Manitoba
THEC	Trail Area Health and Environment Committee
THEP	Trail Area Health & Environment Program
TLAP	Targeted Lead Abatement Program
TPH	Toronto Public Health
TRV	Toxicity Reference Value
TSP	Total Suspended Particulate
TWI	Tolerable Weekly Intake
UBM	Unified Bioaccessibility Research Group of Europe Method
WHO	World Health Organization
WNSW HIU	Western New South Wales Health Intelligence Unit
WRHA	Winnipeg Regional Health Authority
WSDOH	Washington State Department of Health
WTN	Washington Tracking Network
XRF	X-Ray Fluorescence

ASSESSMENT OF ELEVATED LEAD CONCENTRATIONS IN SOIL
IN WINNIPEG NEIGHBOURHOODS

EXECUTIVE SUMMARY

Several investigations were conducted during the 1970s and 1980s to address concerns related to lead exposure in the neighbourhood of Weston and surrounding areas within the City of Winnipeg. A number of sites, including Weston Elementary School, were remediated in the early 1980s in response to the identification of soil lead concentrations that were considered to present a risk to young children. Automobile exhaust from leaded gasoline was identified by several investigations as likely being the main contributor to lead content in Winnipeg soils, with additional contributions from industrial emissions and deteriorating painted surfaces.

Investigations conducted by the Province of Manitoba (the Province) in 2007/2008 and 2018 involved the resampling of areas that were included in the previous studies to determine if lead concentrations had changed since the 1980s. Concentrations were noted to have decreased significantly over this period following the phasing out of leaded gasoline and the closure of three (3) secondary lead smelters in the west end of the City. The most recent investigations have indicated that elevated soil lead concentrations associated with point sources of emissions tend to be localized, while the deposition of lead from the historical use of leaded gasoline has resulted in more widespread contamination along major traffic arteries. These studies have reported lead concentrations above the current Canadian Council of Ministers of the Environment (CCME) residential soil quality guideline of 140 µg/g.

The Province, as represented by the Ministers of Health, Seniors and Active Living and Sustainable Development, retained Intrinsik Corp. (Intrinsik), in association with Habitat Health Impact Consulting, to provide services related to the evaluation of potential human health risks associated with the lead content of soils in neighbourhoods throughout the City of Winnipeg. This also included an evaluation of the benefits of conducting further investigations and recommendations regarding risk management and communication in relation to the measured concentrations of lead. This work was divided into five primary tasks:

- Task 1: Review of available soil investigation data for Winnipeg neighbourhoods;
- Task 2: Review of current and historical records to identify general and point sources of lead within the City;
- Task 3: Review of approaches used by Canadian and Western jurisdictions for addressing lead in soil;
- Task 4: Qualitative assessment of health risks associated with the lead concentrations measured in Winnipeg soils; and,
- Task 5: Recommendations for further assessment of risks and proposed risk management and risk communication options.

<u>Summary of Findings of Task 1 – Review of Available Soil Investigation Data</u>

The Province's review of historical data determined that many of the sites sampled during the investigations conducted in the 1970s and 1980s contained concentrations of lead in soil that exceeded the CCME guideline. As a result, the Province conducted a soil sampling program in 2007/2008 to re-sample these locations with the objectives: (i) of determining if concentrations had significantly changed over this period; and, (ii) to provide a preliminary assessment of current conditions based on a comparison to the CCME guideline. This included the collection of samples from soil depths of 2.5 cm and 5 cm, and from dust from hard surfaces. The results of the Province's investigation indicated that concentrations of lead in soil, sod, and aggregate materials were lower than those measured in the 1980s. The overall general decrease was attributed to the phasing out of leaded gasoline and the closure of the three (3) secondary lead smelters over this period.

Despite the overall decrease in concentrations, five (5) of the six (6) playgrounds sampled in 2007 contained exceedances of the CCME guideline in sod and/or soil samples. No exceedances were identified in areas with aggregate materials, such as sand boxes and areas below swings and play structures. Concentrations of lead had a notable decrease in school yards from the previous sampling event in 1983; however, the Weston Elementary School sports field continued to have elevated concentrations of lead in the sod and the underlying soil. Concentrations of lead in sod and soil samples collected from residential boulevards in the neighbourhoods of Wolseley/Minto, Riverview/Lord Roberts, and Glenelm/Chalmers were notably lower in 2007 relative to 1983, with a small number of sites containing concentrations above the CCME guideline. However, 17 of 23 samples (74%) collected from North Point Douglas contained lead concentrations that exceeded the guideline. The elevated concentrations observed in boulevards in North Point Douglas were likely attributed to both vehicle emissions at major traffic arteries and airborne dust from local scrap yards.

As a follow-up to the 2007 investigation, the Province conducted a supplemental investigation in 2008 which focused on playgrounds and sports fields in areas in the vicinity of potential historical and current point sources of lead. Overall, concentrations of lead were lower than the CCME guideline of 140 µg/g, with only one exceedance out of 90 samples.

In response to public concern, the University of Manitoba, with assistance from the South St. Boniface Residents Association, conducted a soil investigation in fall 2017 that focused exclusively on the neighbourhood of St. Boniface. A total of 174 soil samples were collected at a depth of 0 to 10 cm from commercial, public, and residential properties. This represented the greatest sampling frequency for any of the neighbourhoods sampled to date. Overall, less than 15% of samples contained lead concentrations that exceeded the CCME guideline.

The most recent soil investigation was conducted by the Province in 2018, focusing on locations that were previously sampled during the studies completed by the Province in 2007/2008 and the early 1980s. This investigation was not intended to be an exhaustive study of lead in soil in the City. The objective was to identify any changes in concentrations over time in areas that were included in previous investigations. All samples were collected from a depth of 0 to 7.5 cm, including locations from four (4) residential boulevards (*i.e.*, Wolseley/Minto, Riverview/Lord Roberts, Glenelm/Chalmers, and North Point Douglas), eighteen (18) schools, and thirty-two (32) parks and playgrounds. Exceedances of the CCME guideline were identified at the Weston Elementary School (multiple samples), Westview Park (one sample), and North Point Douglas (multiple samples). Each of these areas were identified as having exceedances in previous investigations.

Following a review of the available data as part of Task 1, the results of the two (2) most recent soil investigations conducted by the Province and the investigation conducted by the University of Manitoba for the neighbourhood of St. Boniface were considered to provide the most applicable soil concentrations for further consideration in the assessment of potential health risks:

- Manitoba Sustainable Development. 2019. Winnipeg Soil Survey, Fall 2018. Environmental Compliance and Enforcement Branch. January 2019.

- University of Manitoba. 2017. Soil Sampling Results from the St. Boniface Area. 2017 (unpublished).

- Manitoba Conservation. 2010. Sampling Report: Surface Soil Lead Levels in Winnipeg, Manitoba: 2007 and 2008. Report No. 2009-03. Winnipeg, Manitoba.

These studies were selected as they were completed following the phase-out of leaded fuels and the closure of the three (3) secondary lead smelters in the City. As a result, they are considered to be more representative of present-day exposures. The sampling methodologies utilized in these studies varied, particularly in regard to the sampling depths which focused primarily on the top 2.5 and 5 cm within the 2007/2008 Provincial study, and the top 7.5 and 10 cm for the 2018 Provincial and 2017 University studies, respectively. This variability presented challenges with respect to comparing sample results between locations and sampling reports, as well as in identifying the most applicable data for evaluating potential human health risks. The leaching of lead is limited due to its tendency to adsorb to soil particles, and since it does not degrade over time, elevated concentrations often persist in surface soils. Generally, soil sampling completed for the purpose of estimating exposure to the general population through incidental ingestion and dermal contact are collected from depths of less than 5 cm below ground surface. As a result, surface soil data provided in the 2007/2008 Provincial study, and the residential data provided in the 2017 University study, were primarily used for further evaluation of risks.

A total of ten (10) neighbourhoods were identified for closer evaluation based on the frequency and magnitude of the exceedances of the CCME guideline of 140 µg/g: Centennial, Daniel McIntyre, Glenelm/Chalmers, North Point Douglas, River/Osborne, Sargent Park, St. Boniface, West End, Weston and Wolseley/Minto. However, the identification of these neighbourhoods as being of potential concern was based on a limited number of samples which may not accurately characterize soil lead concentrations throughout these areas. Additionally, other neighbourhoods may also contain lead concentrations occurring at a frequency and magnitude that represent a potential concern which have not been identified by the available data. Although many of the primary sources of lead emissions are no longer present, the affinity for lead to bind to organic matter in soil will allow lead to persist in surface layers. As a result, the elevated concentrations of lead that were identified in earlier soil investigations are likely to continue to be present in soils that have not been removed or amended since the early 1990s.

<u>Summary of Findings of Task 2 – Identification of General and Point Sources of Lead in Winnipeg</u>

Following the review of the available data describing lead concentrations in soils throughout Winnipeg, the current and historical sources of contamination were evaluated to help further identify areas of potential concern. The review of potential sources of lead in Winnipeg found that historical deposition of lead in various parts of the City were attributable to a combination of sources. Studies conducted by the Province indicated that several older neighbourhoods in the inner City had elevated concentrations of lead in soil that were primarily attributed to the presence of high traffic arteries and the historical use of leaded gasoline. A review of studies of on-road sources of lead found that approximately 75% of lead additives in fuels were emitted within the exhaust. Due to the larger size of vehicle exhaust particles, the majority of emitted lead may have settled within 25 m of a roadway; however, elevated soil concentrations have been identified at distances of up to 100 m.

Several point sources have also been identified as contributing to soil lead levels in Winnipeg. Specifically, the three (3) secondary lead smelters previously operating in the west end of the City. Lead concentrations in soil in close proximity to these secondary lead smelters were frequently 10-fold greater than those concentrations associated with vehicle emissions alone. Numerous additional point sources of lead have also been identified throughout the City, including scrap yards located along Sutherland Avenue in North Point Douglas where elevated lead concentrations were identified within a zone of 60 m. Similar facilities have been identified throughout the inner city. Although these facilities may not have emissions of lead from industrial processes, it is anticipated that airborne particulates created during physical manipulation of lead-containing products may have resulted in localized deposition to surrounding properties. Proximity to rail lines, waste-transfer stations, or other commercial/industrial areas may also result in the accumulation of lead within surface soils. Although lead-based paint is no longer used, older neighbourhoods in the City may still be impacted by its historical use. Lead-based paint from older buildings may deteriorate and peel or chip from painted surfaces, accumulating in soils surrounding the buildings. Areas considered to be hot spots of high lead contamination in soils typically occur within 1 to 2 m of the painted surface. Lead paint particles within interior and exterior dust can represent a significant source of lead exposure.

Based on information available in the investigations conducted by the Province, searches of various databases, and background information provided in the primary literature, numerous potential sources have contributed to concentrations of lead in soils throughout Winnipeg. The largest contributors are anticipated to be the former secondary lead smelters and vehicle emissions from major roadways due to the historical use of leaded gasoline. Given that the smelters have ceased operations, and leaded fuels have been phased-out from use in on-road vehicles, the historical primary sources of lead emissions for neighbourhoods in Winnipeg are no longer present.

Several neighbourhoods throughout the City were identified as being of potential concern due to elevated concentrations reported in the investigations described in Task 1. Based on the identification of numerous additional point sources of emissions, there are a number of areas that were not included within any of the soil investigations which may have received elevated historical rates of deposition. This includes the northeast area of the City where industrial operations were identified as having notable lead emissions, and in the neighbourhoods surrounding the airport. Studies have identified elevated blood lead levels (BLLs) in children living within 1 km of airports where leaded aviation fuel was used. The Canadian Pacific Railway (CPR) Weston Yards, CPR Winnipeg Yards, and the Fort Rouge Yard were also identified as being potential point sources of lead. Several schools (*e.g*., Archwood School, Weston Elementary School, and Fort Rouge School) are in the vicinity of railway lines and yards. Railyards and rail lines may be potential contributors to the elevated concentrations of lead identified in soils in these areas. In addition, given that major roadways are identified as a significant source of historical lead emissions, any neighbourhood that includes major traffic arteries may also represent areas of potential concern.

<u>Summary of Findings of Task 3 – How Canadian and Western Jurisdictions Address Lead in Soil</u>

Task 3 included a review of the approaches used by Canadian and Western International jurisdictions to address concerns related to lead in soil. This review focused on those agencies that have utilized the current understanding of the toxicological effects of lead as a non-threshold contaminant. This review also considered risk management strategies implemented at the federal, provincial, and municipal levels, as well as those recommended by recognized international agencies.

In the last 10 years, several leading international agencies have concluded that neurodevelopmental effects among infants and children is the primary health concern related to lead exposure, with IQ score being the most sensitive of all neurological-related endpoints. There is consensus that these neurodevelopmental effects may occur in association with levels of exposure lower than those previously believed to be safe. Health Canada has recently concluded that selecting children as the most susceptible subpopulation, and neurodevelopmental effects as the most critical endpoint, was protective of other adverse effects of lead exposure (*e.g*., cardiovascular, renal, and reproductive effects) across the entire population. Changes in the weight of scientific evidence regarding these effects has resulted in decreased intervention levels for use by public health organizations for the protection of children's health, as well as lower soil quality guidelines. The current state of science suggests that previous approaches for evaluating lead based on the concept of a 'safe' level of exposure are not sufficiently protective, and that other, non-threshold approaches should be utilized. As a result, comparison of soil concentrations to the current CCME soil quality guideline may not provide an adequate indication of potential risks to young children.

Various case studies for lead contaminated sites in Canada, the United States (US), and elsewhere indicate that the reduction or elimination of emissions is the most effective approach for reducing BLLs in children residing in areas impacted by point-sources. This is consistent with the results of the systematic reviews and literature regarding intervention efficacy which indicate that education on lead exposure and the benefits of good hygiene, and interventions to control dust within households, may influence BLLs when used as part of a larger strategy that includes environmental reduction; however, when used on their own, education and household cleaning may have a limited to no effect on BLLs in children. Due to significant differences in design among studies that examined soil abatement, including removal and replacement, and a combination of interventions (*e.g*., education and dust control), there is generally insufficient data to draw any specific conclusions concerning the effectiveness of soil removal on reducing exposure in children. Given that the primary sources of lead emissions in Winnipeg are no longer present, there is uncertainty regarding the levels of exposure experienced by children in neighbourhoods throughout the City related to historical lead contamination in soil.

<u>Summary of Findings of Task 4 – Assessment of Health Risks of Lead Concentrations in Winnipeg Soils</u>

Based on the review of available soil lead data, the potential sources of lead in Winnipeg neighbourhoods, and the current understanding of lead toxicity, further evaluation of potential exposure and risks was warranted. Understanding the relationship between soil concentrations and exposure in children is important for the assessment of potential risks and the development of environmental guidelines. Task 4 involved a qualitative assessment of potential risks using multiple lines of evidence for the ten (10) neighbourhoods of potential concern identified in Task 1, including:

- Predictive blood-lead modelling based on measured soil data;
- Review of primary literature to identify relationships between soil lead and blood lead; and,
- High-level qualitative evaluation of sociodemographic risk factors that can influence BLLs in a population.

Blood lead levels were predicted using the Integrated Exposure Uptake Biokinetic (IEUBK) model developed by the US Environmental Protection Agency. The assumptions and algorithms used within the IEUBK model are designed to predict the likely distribution of BLLs in young children. However, it must be recognized that the use of the IEUBK model to predict BLLs at a neighbourhood-level is associated with a number of uncertainties, one of which is that it assumes that all children within a given population will be exposed to similar levels of lead under a similar exposure scenario, where in reality the exposures may be much more variable between children.

The IEUBK model was run using arithmetic mean soil concentrations for each of the ten (10) neighbourhoods identified as having soil lead concentrations of potential concern. The concentration of lead in drinking water was set as 0.17 µg/L which represents the average concentration measured in city-supplied treated water in 2018. Given that areas of the City are known to contain homes with lead-containing pipes and plumbing fixtures, the use of a drinking water concentration of 0.17 µg/L may have underpredicted BLLs for some children. The concentration of lead in air was assumed to be 0.002 µg/m^3 which represents the arithmetic mean concentration associated with particulate matter with an aerodynamic diameter less than 2.5 µm ($PM_{2.5}$) as measured in Winnipeg from the most recent reported year (2017). A BLL of 2 µg/dL was selected as a level of concern to be protective of neurodevelopmental risks to children based on the current weight of scientific evidence regarding these effects. For comparison, the results of the 2016-2017 Canada Health Measures Survey, which is reflective of Canadian national averages, reported measured geometric mean BLLs of 0.56 and 0.54 µg/dL for Canadian children ages 3-5 and 6-11 years, respectively.

The predicted geometric mean BLLs for all children under the age of 7 years were found to exceed a level of 2 µg/dL in the neighbourhoods of North Point Douglas (4.7 µg/dL) and Weston (2.6 µg/dL). In North Point Douglas, Weston, and Daniel McIntyre, the predicted BLLs for children within the age groups of 6 months to 1 year, 1 to 2 years, 2 to 3 years, and 3 to 4 years were also at or above 2 µg/dL. In addition, utilizing a standard factor to account for biological and behavioral differences in receptors, as well as variability in repeat sampling and sample analysis, the model predicted that there is a greater than 5% probability (ranging from 7.6% for River/Osborne to 97% for North Point Douglas) that a child will have a BLL exceeding 2 µg/dL in each of the ten (10) neighbourhoods based on the available soil data. Using the 95th percentile soil concentrations, the geometric mean BLLs were above 2 µg/dL for all neighbourhoods considered. Of all the exposure pathways included in the model (food, water, soil, dust, air, maternal transfer), soil/dust was found to contribute the most to the predicted lead exposures in children under the age of 7 years (up to 94% for children aged 1 to 2 years in North Point Douglas).

While these results may provide a general idea of the average neighbourhood risk potential, a more accurate method to assess risk may be to consider soil concentrations on a property by property basis. The results of the IEUBK modelling, using an ambient outdoor air concentration of 0.002 µg/m^3, a drinking water concentration of 0.17 µg/L, and standard exposure estimates associated with lead in a North American diet, indicate that a soil lead concentration of approximately 165 µg/g will result in a geometric mean BLL of 2 µg/dL, and a soil concentration of 50 µg/g is associated with a 95% probability that a BLL will be below 2 µg/dL. Given that St. Boniface is the only neighbourhood for which sampling was conducted on residential properties, soil results from this neighbourhood were used to identify the general proportion of properties that may contain soil lead concentrations that exceed these values. Approximately 50% of the sampled residential properties contained concentrations of lead that exceeded 50 µg/g, while approximately 12% exceeded a concentration of 165 µg/g. Similarly, the results of the

2007/2008 Provincial soil investigation indicate that 91% of surface soil samples collected from boulevards in the neighbourhood of North Point Douglas contained concentrations that exceeded 50 µg/g, and 74% of samples exceeded 165 µg/g. Assuming that concentrations measured along these boulevards are reflective of conditions on residential properties, a significant proportion of this neighbourhood may contain soil lead concentrations that exceed these values. This may also be true for other Winnipeg neighbourhoods that have not been characterized with the same sampling intensity.

Overall, the results of the IEUBK modelling indicate that the potential for children's BLLs to exceed a level of concern are relatively low for many of the neighbourhoods for which soil lead results are available, particularly given that most of these areas do not have a significant active source of lead emissions. Many studies have demonstrated significant decreases in BLLs following a reduction or elimination of emissions despite the continued presence of elevated concentrations in soil. There are numerous areas of uncertainty associated with characterizing opportunities for exposure to soil contamination resulting from historical emissions. However, there is a greater potential for children to have elevated BLLs in the neighbourhoods of North Point Douglas and Weston as a result of the frequency of elevated soil lead concentrations in these areas.

Given that modelling of BLLs was only conducted for those neighbourhoods that were identified as having 10% or more of samples with concentrations that exceeded the CCME guideline, there are several additional neighbourhoods where sampling has occurred where the potential for elevated BLLs are considered to be low. It must be noted however, that the available sampling data for these and most other Winnipeg neighbourhoods may not be representative of soil concentrations on residential properties throughout these areas. Sampling conducted by the Province was restricted to public lands including boulevards, parks, and schools. In particular, sampling from the Weston neighbourhood was heavily focused on the Weston Elementary school yard which may or may not be representative of the variability of concentrations throughout this neighbourhood. The soil investigation conducted by the University of Manitoba for the neighbourhood of St. Boniface consisted of the collection of 174 samples, including sampling on approximately 150 residential properties. As a result, the variability in soil lead concentrations in this neighbourhood is probably more accurately characterized than for other neighbourhoods.

Given the theoretical nature of modelling BLLs based on assumptions of exposure, uptake, and biokinetics, studies in which lead exposure have been measured *via* blood lead analysis and used to establish a correlation between BLLs and concentrations of lead in soil were also considered. Empirical results are often used to generate a regression or slope factor relating changes in BLLs with soil or other environmental lead concentrations. Slope factors generated using empirical data reflect site-specific and study-specific exposure scenarios, and as a result there is inherent uncertainty in applying these factors to other sites. Therefore, the relationships between soil concentrations and BLLs identified within these studies were used to provide a qualitative assessment of potential risks to Winnipeg residents. Given that automobile exhaust from leaded gasoline is interpreted to be the main (past) contributor to lead content in soils of central areas of Winnipeg, this was an important consideration in the identification of comparable neighbourhoods.

A review of numerous studies describing the empirical association between soil lead concentrations and BLLs in children have shown significant and strong associations between the two variables on a case-by-case basis. Some models report a linear relationship between soil lead and BLLs, with slopes indicating that for every 1,000 µg/g increase in soil lead there is an increase in children's BLL of 1.3 to 1.5 µg/dL. Other studies have reported a curvilinear relationship in which BLLs increase at a much steeper rate at lower soil concentrations (1.4 µg/dL per 100 µg/g) followed by a more gradual increase at higher concentrations (0.32 µg/dL per 100 µg/g). It is important to note that relationships varied significantly across studies, and other factors, including seasonal variability and child age, can have a large impact on lead exposure in children.

The slope predicted using the IEUBK model is greater than those derived using empirical data, however, at soil lead concentrations below 100 µg/g the IEUBK model predicted lower BLLs than the empirical relationships which may be related to the assumption of low exposures related to air and drinking water in Winnipeg. At relatively low soil lead concentrations, the curvilinear relationships identified in several studies may be the most applicable models for many Winnipeg neighbourhoods. These relationships demonstrate that BLLs increase at a sharper rate at soil lead concentrations below 100 µg/g, followed by a more gradual increase around 300 µg/g. Use of these models would predict geometric mean BLLs of greater than 2 µg/dL at concentrations below 100 µg/g, indicating potential concerns for several Winnipeg neighbourhoods, however, it is unknown if non soil-related exposures in the neighbourhoods that these relationships were based on are similar to those in Winnipeg. As a result, there is uncertainty in the application of the empirical results to predict BLLs in Winnipeg neighbourhoods.

Contributing to the uncertainty associated with predicting BLLs and the effects of lead exposure in Winnipeg children is the relatively lower socioeconomic and health status ratings for some of the neighbourhoods identified as having elevated soil lead concentrations. This includes North Point Douglas, Weston, Daniel McIntyre, and Centennial, which share similar characteristics including lower income, lower rates of employment, lower levels of education, higher proportion of Aboriginal and visible minority residents, and lower ratings than for the overall City of Winnipeg for several indicators of health (*e.g.*, disease prevalence, birth weight, mortality rates, life expectancy). As a result of these findings, the children living within the areas of Point Douglas (which includes North Point Douglas), Inkster (includes Weston), and Downtown (includes Daniel McIntyre) may be more vulnerable to the effects of lead toxicity than children in other areas of the City.

<u>Summary of Findings of Task 5 – Recommendations for Further Assessment and Risk Management Options</u>

To aid the Province in identifying potential actions to address health concerns related to lead in Winnipeg soils, a general overview of options was conducted as part of Task 5. This included consideration of approaches for further investigation, risk management, and public outreach. Given that the current CCME guideline is not based on the most recent scientific evidence regarding lead toxicity, preliminary calculations were made for site-specific remediation criteria based on a range of recently endorsed non-threshold-based toxicity reference values and literature-based bioaccessibility estimates. This resulted in a range of values for a residential soil guideline of 100 to 210 µg/g using a standard CCME approach based on central tendency estimates. The current CCME guideline of 140 µg/g falls within this range. However, use of an approach that accounts for probability distributions of BLLs, such as those estimated using the IEUBK model, may result in a residential soil lead criterion well below 100 µg/g.

Based on the information available to describe lead content in soils in various neighbourhoods throughout Winnipeg, the completion of a quantitative human health risk assessment (HHRA) is unlikely to provide significant further insight into the interpretation of potential risks. Additional investigations focusing on characterizing the distribution and bioaccessibility of lead in soils, as well as lead content in other environmental media such as indoor dust, at-tap drinking water, and painted surfaces, would be required to realize the full potential benefits of conducting a detailed HHRA.

Several potential risk management and remediation activities are available for lead. Each option is associated with various benefits and challenges and should be considered carefully with respect to the potential risks and benefits of implementing these options on a site-by-site basis. Information available from case studies and the literature suggest that a reduction in the source of lead exposure within neighbourhoods through emission reduction or elimination, or soil-capping/remediation, are the most effective measures for reducing BLLs. Household abatement, indoor dust management and hygiene practices appear to be generally less effective when used on their own. Given that the primary sources of lead contamination for Winnipeg soils have been eliminated (*e.g.*, leaded fuels, secondary lead smelters), further source reduction would likely be limited to isolated commercial/industrial operations.

Overall, using multiple lines of evidence, including characterizing the frequency and magnitude of exceedances of health-based soil criteria, theoretical modelling of BLLs, and extrapolation of empirical data to relate soil concentrations to potential BLLs in Winnipeg children, the assessment of potential risks associated with soil lead concentrations indicates that further study may be warranted. Given that there are sufficient data to demonstrate that soil contamination in certain neighbourhoods represents a potential concern, blood lead monitoring is recommended as an effective approach for assessing risks and the potential need for further soil sampling and/or the implementation of risk management measures. For the neighbourhoods of Weston and North Point Douglas, the available soil data indicates that there is a higher probability of elevated BLLs for children living in these areas. For these neighbourhoods, the combination of elevated soil concentrations and lower socioeconomic status creates greater concern for health risks. Biomonitoring in these areas will help to determine if similar studies are needed for other neighbourhoods throughout Winnipeg.

In addition to the collection of blood for lead analysis from children under the age of 7 years, a detailed questionnaire for participants is recommended to collect information about their environment and various personal factors that may influence exposure to lead. The collection of environmental samples from individual households of participants can also be included as part of the study to examine the potential influence of various environmental media on levels of internal exposure.

<u>Recommendations</u>

Based on the findings of the work completed in Tasks 1 to 5, recommendations are provided for consideration by the Province related to risk communication, risk management, and further investigation of potential human health risks associated with lead in soils within the City of Winnipeg.

Recommendation 1: Community Outreach and Education.

It is recommended that the Province, in collaboration with key stakeholders (including but not limited to the City of Winnipeg), develop an overall lead awareness communication program. This program should develop opportunities to communicate the potential for lead exposure, the potential health hazards in Winnipeg, and options for reducing exposure to lead. A central repository for information should be maintained on a dedicated website with social media linkages. All reports, presentations, factsheets, status updates, and press releases could be shared on such a website, including the final version of this assessment as well as all historical reports characterizing lead in soils in Winnipeg. This may be an expansion of the existing "*2018 Winnipeg Lead in Soil Survey*" page (https://www.gov.mb.ca/health/publichealth/environmentalhealth/wlss.html) which already includes links to numerous fact sheets and historical reports. Practical approaches for reducing exposure to lead are already provided on this website, focusing on all potential sources including soil, home gardens, drinking water, paint, and hobbies. This website and related social media platforms could also provide an opportunity for residents to submit written questions or concerns to be addressed by a public health representative in Winnipeg (in addition to the current opportunity to call a health care provider or Health Link representative *via* the phone numbers provided). The website should be updated on a regular basis and provide an opportunity for health officials to address new and emerging concerns related to lead circulating in the news and on social media (*e.g.*, new studies on lead in drinking water throughout Canada, release of the findings of the City of Winnipeg's drinking water study).

Factsheets

The Province has existing factsheets regarding general lead exposure and risks, soil lead exposure and risk to Winnipeg residents, as well as exposures related specifically to gardening. As part of a city-wide communications strategy that could begin at any time, this information should be updated and shared widely. Based on the technical aspects of the literature reviewed within this report, suggested edits are provided below.

For the general lead factsheet, it is suggested that additional information and recommendations include:

- Covering bare, unamended soils on residential properties, including gardens and lawns with inconsistent grass cover. This may include the addition of new sod to lawns, or mulch, rocks, or other materials to gardens;
- The provision of preferred areas for children to play (*e.g.*, raised sandbox, play structures);
- Thorough and regular cleaning of toys and pacifiers used by children;
- Use of doormats at house entrances and consistent removal of outdoor footwear at entranceways;
- Regular wet mopping of floors and the use of vacuums with HEPA filters; and,
- General information regarding home gardening (beyond the link provided to ensure that people read the necessary information).

For the gardening factsheet, it is suggested that additional information and recommendations include:

- Limit or prevent children from entering gardens if contaminant levels are unknown;
- If contaminant levels are unknown, or the area is known to have elevated lead concentrations in soil, reduce or eliminate practices that bring deeper soils to surface such as aeration or tilling, or those that can re-distribute dusts (*e.g.*, leaf-blowing);
- If unsure or concerned regarding garden food exposures, consider planting ornamental plants and ground coverings; and,

- If soil pH is found to be below 6.5 or above 7.5, apply soil treatments to adjust soil to neutral pH (*e.g*., between 6.5 and 7.5).

Training for Daycares, Community Centres, Preschools, Schools and Parents Regarding Lead Exposure Prevention

The lead awareness campaign could include training on hand washing and hygiene, including the distribution of kits to parents and caregivers. This program could be similar to that created for Flin Flon where a hand washing "super hero", *Mighty Bubble*, appeared at events and his character was incorporated into a handwashing "toolkit" that was distributed to all kindergarten to grade 2 students, as well as to all children at public daycare centres in the community. Similar toolkits containing resources for parents and caregivers can be distributed to children after participating in workshops led by community health care workers.

Recommendation 2: Biomonitoring and Paired Environmental Sampling Study

Based on the results of the literature review and predictive blood lead modelling, a number of neighbourhoods were identified as having soil lead concentrations that may be associated with elevated risks to residents. Given these findings and the uncertainties related to theoretical risk estimates and the limited soil sampling data for residential properties, it is recommended that a biomonitoring study be completed with paired environmental sampling (of soil, drinking water, interior paint, and dust) for residences with children under the age of 7 years with the objective of measuring actual levels of lead exposure. This will help determine if exposures experienced by young children represent a potential health concern. Such a study could be part of a larger lead management and communication strategy by the Province in partnership with other stakeholders (*e.g*., the City of Winnipeg) to address overall lead exposure (*e.g*., including drinking water). It is recommended that this study include neighbourhoods within the identified priority areas of:

1. **Point Douglas** (specifically North Point Douglas, South Point Douglas, and neighbourhoods to the west and north that have not been sampled for lead to date). This area has been identified as having elevated soil lead concentrations above what has been reported in urban areas where lead has been identified as a potential concern in other parts of the world. The soil measurements to date have been focused on a small area of Point Douglas. Using the IEUBK model, the predicted geometric mean BLL for the neighbourhood of North Point Douglas was 4.7 µg/dL. A significant proportion of soil samples collected from residential boulevards in this area contained lead concentrations that exceeded values derived to be protective of a BLL of 2 µg/dL. Further, due to the proportion of young children in this neighbourhood and the low socioeconomic and health status of the area, biomonitoring and environmental sampling in this area should be given particular priority.

2. **Inkster** (specifically Weston, as well as Burrows Keewatin which has not been sampled to date). This area is highlighted due to its proximity to several historical emission sources and the identification of elevated soil lead concentrations at Weston Elementary School. Using the IEUBK model, the predicted geometric mean BLL for the neighbourhood of Weston was 2.6 µg/dL. These results are based on soil samples collected from the Weston School which has undergone multiple rounds of remediation. Higher concentrations may exist on residential properties in the surrounding area. An alternative approach may be to complete biomonitoring and environmental sampling for

Weston to characterize exposure and identify the need for risk-mitigation measures, and to complete only soil sampling within Burrows-Keewatin to determine the need for any future biomonitoring in this area.

The areas listed above for proposed future study include neighbourhoods located in proximity to major roadways, current or historical industrial emission sources, and areas with older housing that may have lead paint and lead-containing plumbing and fixtures. It may also be of value to extend the biomonitoring study into the Downtown area (*e.g*., Daniel McIntyre) given the limited extent of sampling coverage in this area.

The aim of the biomonitoring study is to measure the actual levels of exposure experienced by children in the selected neighbourhoods of potential concern. In the event that the study identifies children with elevated BLLs that represent a health concern, appropriate risk mitigation strategies can be developed on an individual level with the assistance of medical and public health personnel to reduce their overall exposure to lead. The environmental sampling of the households of participating children included in a biomonitoring study is intended to capture individual exposure hazards, as well as to provide information regarding sources of lead exposure on a residence-to-residence basis such that the need for community-wide action can be more clearly evaluated.

The findings of the biomonitoring and environmental sampling may reveal the need for additional study in other areas of Winnipeg. It is also suggested that one or two neighbourhoods from outside the central core area of Winnipeg that are of reflective of the socioeconomic and health status of the City of Winnipeg as a whole are included as a control group for comparison.

Recommendation 3: Weston School and Playgrounds.

It has been requested that a specific course of action be recommended for the Weston Elementary School based on the extent of sampling completed to date. Despite the elimination of the primary historical sources of lead emissions (*i.e*., the Canadian Bronze smelter and leaded fuels), and the completion of a number of remediation activities, elevated concentrations of lead continue to be identified in soils on this property. Ongoing contamination of soils and sod may be related to the re-distribution of particulates from adjacent properties. Elevated concentrations of lead were identified in the school yard in the most recent Provincial study at a frequency and magnitude that warrants further investigation and potential risk management. Given that the winter 2019/2020 season is commencing which will restrict access to impacted soils due to frozen ground and snow cover, the implementation of immediate risk management measures is not considered to be necessary. However, it is recommended that students, parents, and staff are made aware of the potential concerns related to lead in soils on the school grounds and are provided with an overview of the potential future actions that are being considered by the Province.

In order of priority, recommended actions for the Weston school yard and sports field include:

- Promote hand washing and hygiene at the school (as well as to potential park users, including area day cares and day homes) through an awareness campaign, and the distribution of kits to parents and caregivers regarding handwashing and lead awareness;

- The collection of surface soil and sod samples following the spring thaw at a depth of 0-2.5 cm to characterize current surface soil conditions. Any visibly exposed areas of soil or aggregate should be sampled;

- Before the time of the first period of lawn maintenance in the spring/summer, the maintenance staff at the school (and also other parks in the Weston area) should be instructed to take measures to minimize the generation of dust or exposure to underlying soils during landscaping maintenance (*e.g*., aeration, leaf blowing);

- Replacement of dust-generating sand or gravel in the playground area with a soil barrier or solid rubberized playground surface material. If a barrier/rubber material are not installed, consideration should be given to regular replacement of sand/gravel over time. Wipe samples can be collected from hard surfaces (including playground equipment) and analyzed for lead content (before and after the implementation of any mitigation measures) on an annual or seasonal basis;

- Exposed soil surfaces should be covered in mulch, sod, or groundcover to prevent direct access to soils and the generation of dust; and,

- Dependent on the findings of the supplemental sampling of soil, sod, and hard surfaces, the replacement of grass with artificial turf for the sports field could be considered. This will act as a complete barrier to any underlying impacted soils. Dust control measures must be implemented during any excavation and installation procedures to reduce the re-suspension of impacted materials which may be re-deposited on the new artificial surfaces or adjacent properties. If installed, the turf should be cleaned and maintained as per the manufacturer's instructions, with any solid or liquid waste from the turf contained and disposed of appropriately off-site.

Several of the above listed risk-mitigation measures could also be proactively taken for the other schools, playgrounds, and recreational areas within the Weston neighbourhood on a case-by-case basis with the overall aim of reducing the potential for soil and outdoor dust exposure for young children.

Recommendation 4: Blood Lead Reporting and Monitoring.

Currently, elevated blood lead is not considered to be a reportable disease in Manitoba, and in the event that a family doctor requests that a child be tested for lead exposure, there is no tracking of this at a public health level. A reporting system that ensures that any children in the province who are tested by their family physician or other public health personnel are tracked and receive any necessary follow-up may assist public health officials in identifying clusters of children who are potentially being adversely affected by lead.

Uncertainties and Limitations

The identification of neighbourhoods as being of potential concern was based on a limited number of samples which may not accurately characterize soil lead concentrations throughout these areas. Additionally, other neighbourhoods may also contain lead concentrations occurring at a frequency and magnitude that represent a potential concern which have not been identified by the available data. Significant gaps in the soil data are apparent in the areas immediately surrounding the railway line, particularly on the north side between McPhillips and Main Streets, to the north of Dufferin and Dufferin Industrial. This area includes a large portion of the Point Douglas Community Health Area and an area of the City known as the 'north end'. While data for North Point Douglas, Dufferin, and Dufferin industrial, and a few data points for South Point Douglas are available, there is an overall lack of coverage.

The Weston area data set is also affected by the lack of residential samples. All available data are for samples collected from the elementary school or sports field, and a few playgrounds. While these are of relevance to school-aged children, they do not necessarily capture the exposures that children under the age of 6 years may be receiving at home or in childcare. The data is clustered and does not provide full coverage of the neighbourhood as a whole. Further, numerous samples for Weston were collected at a depth of 0-7.5 cm rather than 5 cm or less.

There are some notable data gaps for the neighbourhoods within the Downtown area of Winnipeg. All of the available information for Daniel McIntyre (also considered be part of the Downtown Community Health area) is clustered within area parks, without any coverage of residential areas. Most of the soil data available for the neighbourhood of Centennial was collected from the Dufferin Elementary School and did not include areas more representative of residential exposures to which young children could be exposed. Several samples were collected in Wolseley/Minto and Sargent Park from schools, community centres and residential boulevards, however, no samples have been collected from residential properties in these areas either. No residential area data are available for the other areas that fall within the Downtown Community Health Area – Central Park, Assiniboine, West Alexander, West Broadway and Spence or St. Matthews (located to the south). While it is acknowledged that this area is less residential than some of the other neighbourhoods evaluated, the 2016 census data indicates that there are children residing in these areas.

The data set for the neighbourhood of St. Boniface is the largest out of all of the neighbourhoods evaluated in this assessment. The St. Boniface data from the investigations conducted by both the Province and the University of Manitoba are focused on soil samples from a depth of 0-7.5 or 0-10 cm, rather than less than 5 cm as recommended for the health assessment of lead. Soil sample locations were inconsistent, with many of the St. Boniface samples collected from gardens. It is likely that garden soils are amended to some extent with soils obtained from other areas (*e.g.*, topsoil, manure, compost, mulch, etc.) and as a result, there is uncertainty regarding the use of these samples to represent soil lead concentrations on a given property.

There is a large degree of uncertainty in utilizing relationships between soil lead and blood lead identified from other studies or estimated using the IEUBK model to predict BLLs in children in a neighbourhood of interest. The assumptions and algorithms used within the IEUBK model are designed to predict the likely distribution of BLLs in young children. Use of the IEUBK model for a neighbourhood-based assessment has limitations in that it assumes that all children within a given population will be exposed to homogenous levels of lead under a similar exposure scenario. In reality, there may be significant variability in the lead concentrations in media such as indoor dust and backyard soil across properties within any given neighbourhood. The use of empirical results to provide an indication of BLLs based on soil concentrations also has several limitations and uncertainties given that there are inherent assumptions regarding similarities in soil lead bioaccessibility, characteristics of the exposed population, and non soil-related exposures.

The current assessment addressed potential risks associated with concentrations of lead measured in soil in inner city Winnipeg but did not evaluate or provide recommendations for methods to prevent future and ongoing contamination. New and revised policies related to sources of lead, industrial setbacks, emissions and air quality objectives, and licensing approvals may also result in improvements related to lead in soil. Such decisions should be made in consultation and partnership with municipalities, communities and industry.

1.0 INTRODUCTION

Concern over exposure to lead in inner city Winnipeg appears to have been initially triggered in 1975 by the identification of elevated blood lead levels (BLLs) in workers at a Winnipeg foundry. Exposures related to the casting of lead alloys resulted in a number of workers requiring medical intervention. Atmospheric releases of lead from this facility, as well as exhaust emissions from heavy vehicular traffic, raised concerns regarding the health status of residents in the surrounding Weston neighbourhood. A blood lead study conducted on students from the Weston Elementary School in 1976 identified elevated BLLs relative to those found in students from a school selected as a control (Lord Nelson Elementary School). These findings resulted in numerous investigations being conducted in Weston and surrounding neighbourhoods in Winnipeg to characterize concentrations of lead in soils. A number of investigations conducted by the Province of Manitoba (the Province) and other researchers concluded that elevated concentrations of lead in Winnipeg soils are primarily attributed to leaded gasoline from vehicle exhaust.

The initial comparison of soil lead results was made to a criterion of 2,600 µg/g (equivalent to 2,600 mg/kg or 2,600 ppm) which was adopted from the applicable Ontario Guidelines at the time the soil investigations were completed (Jones, 1985). Concentrations of lead measured in samples collected from boulevards, school yards, parks, and playgrounds generally met this guideline, with the exception of numerous samples collected from the Weston Elementary School. A number of sites, including Weston Elementary School, were remediated in the early 1980s in response to the identification of concentrations in excess of this guideline as these soils were considered to represent a risk to young children (Jones and Wotton, 1982, 1983b; Jones, 1985, Manitoba Conservation, 2010). The Canadian Council of Ministers of the Environment (CCME) updated the Canadian Soil Quality Guidelines (SQGs) for the Protection of Environmental and Human Health in 1999 and an SQG of 140 µg/g was established for lead to be protective of human health from soil ingestion for residential/parkland properties. Investigations conducted by the Province in 2007-2008 and 2018 resampled areas that were included in the previous studies to determine if lead concentrations had changed since the 1980s. Concentrations were noted to have decreased significantly over this period following the phasing out of leaded gasoline and the closure of three (3) secondary lead smelters in the west end of the City. The most recent investigations have indicated that elevated soil lead concentrations associated with point sources of emissions tend to be localized, while the deposition of lead from the historical use of leaded gasoline has resulted in more widespread contamination along major traffic arteries (Manitoba Conservation, 2010).

Since the derivation of the CCME SQGs for lead in 1999, there have been significant changes in the understanding of the toxicological effects of lead in children and adults. This has resulted in a re-evaluation of what is considered to be a “safe” level of lead in terms of exposure, and changes to how BLLs are interpreted and managed. Up until 2013, the level of concern (or intervention level) for BLLs in Canada was 10 µg lead per decilitre of blood (µg/dL). As of 2013, this value was no longer considered to provide adequate protection (Health Canada, 2013a). A new reference value has not been established by Health Canada to date.

In light of an increasing body of scientific research demonstrating a broad spectrum of health outcomes associated with lead exposure, most notably neurological effects among children at low BLLs (*i.e.*, less than 10 µg/dL), various regulatory agencies have updated their respective health-based policies and guidelines concerning lead. Much of these regulatory changes stem from the evolving science on the toxicology of lead, and the opinions by numerous regulatory agencies and scientific studies that a threshold for effects for lead cannot be determined, and hence, that there is risk at any level of exposure (Health Canada, 2013a; US EPA, 2006; WHO, 2010c, JECFA, 2011). As a result, there is no longer a "safe limit" of exposure to lead (a level below which adverse effects are not anticipated to occur). Hence, the blood lead "action level" or "intervention level" has been reassessed, as have various guidelines or benchmarks related to management of lead in air, soil, and drinking water.

Many international agencies, including Health Canada (2013a), have indicated that the relationship between IQ score (in children) and BLLs is the strongest line of evidence of adverse effects in humans at BLLs of less than 10 µg/dL. Neurodevelopmental effects among infants and children is the primary health effect of concern, with IQ score being the most sensitive of all neurological-related endpoints. Health Canada has concluded that selecting children as the most susceptible subpopulation, and neurodevelopmental effects as the most critical endpoint, was protective of other adverse effects of lead exposure (*i.e*., cardiovascular, renal, and reproductive effects) across the entire population.

Blood lead levels of Canadians have declined significantly over the past 30 years. However, in response to the evidence that health effects are occurring at levels below 10 µg/dL, and in consideration that it is appropriate to apply a conservative approach when characterizing risk, additional measures to further reduce exposures of Canadians to lead are warranted (Health Canada, 2013b). Accordingly, the overall Government of Canada risk management objective for lead is to reduce exposure to lead to the greatest extent practical by strengthening current efforts in priority areas where the government can have the greatest impact upon exposure of Canadians.

The Province, as represented by the Ministers of Health, Seniors and Active Living and Sustainable Development, retained Intrinsik Corp. (Intrinsik), in association with Habitat Health Impact Consulting, to provide services related to the evaluation of potential human health risks associated with the lead content of soils collected from residential areas within the City of Winnipeg, and to provide recommendations regarding further investigation, risk management, and public engagement. This project was divided into five (5) primary Tasks identified within the Scope of Work outlined within the Request for Proposal #MHSAL-2019-001.

Tasks 1 to 3 represented an information gathering stage that were used to support the assessment of potential risks to residents of Winnipeg. Task 1 involved a review of the available investigations and data describing the characterization of lead content in Winnipeg soils. Task 2 included a review of current and historical records to identify general and point sources of lead emissions within the City of Winnipeg. Federal and provincial registries and databases were utilized to identify past and current facilities releasing lead in large quantities to the environment. The results of this Task were used to identify areas within the City that may have experienced elevated or unique opportunities for the deposition of lead to soils. Task 3 included a review of the approaches used by Canadian and Western International jurisdictions for addressing concerns related to lead in soil, focusing on those that have utilized the current understanding of the toxicological effects of lead as described above. This review considered risk management strategies implemented at the federal, provincial, and municipal levels, as well as those recommended by international agencies such as the US Environmental Protection Agency (US EPA) and the World Health Organization (WHO). A focused search of the peer-reviewed published literature was also conducted, identifying studies published after Health Canada's preparation of their "Final Human Health State of the Science Report on Lead" (Health Canada, 2013a), that relate to the assessment of lead in soil and potential human exposure and health risk.

Task 4 included a qualitative assessment of health risks associated with concentrations of lead measured in Winnipeg soils. This was accomplished by considering the relationship between soil concentrations and exposures in children as identified using theoretical models to predict exposure and uptake, and through consideration of empirical results generated by studies in which both environmental concentrations and exposures were measured. These results were used in Task 5 to assess the need for risk management measures, provide options for risk communication and public engagement strategies, and a discussion of the potential benefits of further investigations such as human health risk assessment (HHRA) or biomonitoring.

This report has been arranged by Task, with an initial summary followed by a more detailed discussion of the findings for each. Additional summaries, search strategies, and data tables are provided in appendices.

The current assessment addressed potential risks associated with concentrations of lead measured in soil in inner city Winnipeg but did not evaluate or provide recommendations for methods to prevent future and ongoing contamination. New and revised policies related to sources of lead, industrial setbacks, emissions and air quality objectives, and licensing approvals may also result in improvements related to lead in soil. Such decisions should be made in consultation and partnership with municipalities, communities, and industry.

2.0 TASK 1: EVALUATION OF CURRENT AND HISTORICAL DATA FOR LEAD IN WINNIPEG SOILS

Numerous investigations characterizing lead content in soils have been completed within the City of Winnipeg over the last four decades. Automobile exhaust from leaded gasoline has been identified by several investigations as likely being the main contributor to lead content in Winnipeg soils, with additional contributions from industrial emissions and deteriorating painted surfaces. A detailed review was conducted of each of these investigations. Information gathered as part of this exercise was used to evaluate the adequacy of the existing data to assess exposure and risk to people residing in various neighbourhoods throughout Winnipeg.

The sampling methodologies utilized in these investigations were considered when evaluating the relevance of the data for characterizing potential exposure to receptors. This includes the depth at which samples were collected to determine if they are representative of soils that may be encountered on a regular basis by children and other age groups during normal daily activities. Samples that were collected well below ground surface or from areas where there is a continuous barrier that would prevent or significantly limit opportunities for human contact during routine behaviour may not be suitable for assessing chronic exposure and risks to residents.

The leaching of lead is limited due to its tendency to adsorb to soil particles, and since it does not degrade over time, elevated concentrations often persist in surface soils (ATSDR, 2019). Generally, soil sampling completed for the purpose of estimating exposure to the general population *via* incidental ingestion or dermal contact are collected from depths ranging from ground surface to 2.5 cm or potentially 5 cm below ground surface. Samples are typically composed of a composite of multiple individual soil cores collected from within a small defined area that is likely to be used by residents (particularly children) on a frequent basis (*e.g.*, backyards, playgrounds, school yards). There may be justification for excluding data collected from sampling locations that are not representative of areas of this nature (*e.g.*, subsurface samples collected to delineate contaminated sites).

The primary intention of the assessment was to characterize potential exposure and risks to the general population of urban areas of Winnipeg. Therefore, the nature of the investigations and the sampling strategies were reviewed to determine if the identified lead contamination was associated with property-specific sources that would not be representative of conditions across the neighbourhood. This includes investigations that were conducted for the purpose of characterizing contamination associated with above ground or underground storage tanks used for commercial or residential heating, retail fuel outlets, bulk fuel storage facilities, or other commercial industrial properties with localized contamination related to spills or on-site activities that are not anticipated to impact surface soils in the surrounding neighbourhood.

Following the exclusion of any data that was not considered to be appropriate to be used in the assessment of potential risks to human health, an overall data gap analysis was conducted to describe areas of uncertainty in the characterization of soil lead content throughout the study area. This included an analysis of the nature of the distribution of lead content in soils and the description of statistical parameters of the data set that were used in the evaluation of health risks. These results were used to complete a preliminary screening-level assessment of risks by comparing soil concentrations to health-based soil quality guidelines with consideration given to the magnitude and frequency of any exceedances. A summary of the findings of Task 1 is provided in Section 2.1. A more detailed review of the individual investigations is provided in Section 2.2.

2.1 Summary of the Findings of Task 1

This section provides an overview of the historical and more recent soil investigations completed by the Province and other researchers. Only a sub-set of the soil data collected was selected for inclusion for further screening and analysis. This selection is described further within Section 2.1.3 followed by a discussion of uncertainties and data gaps in Section 2.1.4.

2.1.1 Background

Following the identification of elevated BLLs in foundry workers and students in the Weston neighbourhood in the mid-1970s, a series of investigations were conducted by the Province in the 1970s and 1980s to characterize lead content in soils and other environmental media (*e.g.*, sod, sand, vegetation, and dust from hard surfaces) in the inner city of Winnipeg. These investigations indicated that concentrations of lead generally met the then applicable guideline of 2,600 µg/g in soil samples collected from boulevards, school yards, parks, and playgrounds in several neighbourhoods, although concentrations from numerous locations exceed the current CCME guideline for lead in residential soils of 140 µg/g (additional information regarding this guideline value is provided within Section 4.2.2.3.1). The notable exception was the identification of concentrations of lead that exceeded the guideline of 2,600 µg/g in particulates from the paved play area at the north side of the Weston Elementary School in 1980 and 1981, with an average concentration of 4,850 µg/g (Jones, 1985). In response, a dry vacuuming procedure was used to remove approximately 1.0 tonne of debris in 1981. Ongoing monitoring in 1982 and 1983 identified that lead concentrations in debris once again exceeded the guideline. Dry vacuuming removed an additional 1.36 tonnes of debris in 1983 (Jones, 1985). Given that deteriorating lead paint was suspected to be contributing to the elevated concentrations of lead in debris at the Weston Elementary School, all painted surfaces on the north and west sides of the school were scraped and repainted in the summer of 1984. This was followed by the removal of the paved ground surfaces adjacent to Logan Avenue at the front of the school and along Quelch Street on the west side of the property. New soil, sod, trees, and shrubs were added to these areas. Despite these efforts, lead concentrations in excess of the current guideline were identified during the subsequent studies conducted at the school in 2007/2008 (Manitoba Conservation, 2010) and 2018 (Manitoba Sustainable Development, 2019).

Three (3) secondary lead smelters previously operated in the west end of the City (Figure 2-1). The Canadian Bronze Co. Ltd. (Canadian Bronze) smelter was located on Bury Street north of Logan Avenue in the Weston neighbourhood, in close proximity to the Weston Elementary School and numerous residential properties. This facility closed in the 1990s and the property was remediated in 1999-2000. The Canada Metal Co. (Canada Metal) smelter was located at St. James Street and Wellington Avenue in the St. James Industrial Park neighbourhood. The properties immediately surrounding this facility are commercial/industrial in nature. The smelter operated from 1954 to 1976, and battery storage and smashing activities occurred from 1954 to 2002. All operations at this facility ceased in 2002 and the area was remediated in 2004. The Northwest Smelting Co. (Northwest Smelting) smelter was located at the west end of Logan Avenue, an area that is also surrounded by commercial and industrial properties (Manitoba Conservation, 2010). The smelter ceased operations in early 2000s and the site has since been remediated.

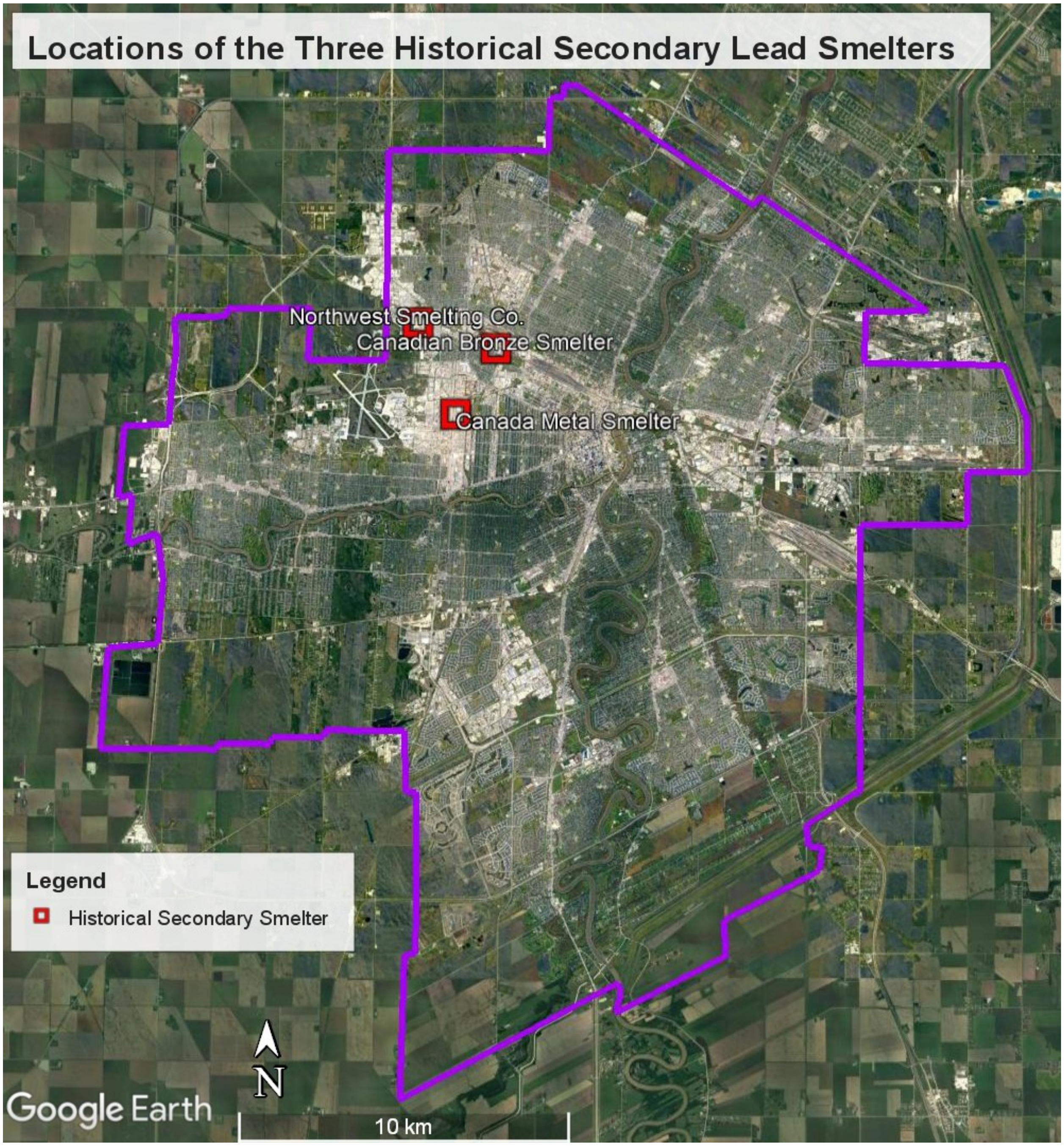


Figure 2-1 Locations of the Three Secondary Lead Smelter Sites in Winnipeg, MB

The efficacy of the pollution control devices utilized by the three (3) secondary lead smelters were suggested to have been limited, including a period in which there was uncontrolled emissions from the Canada Metal facility due to a stack knock-down (date not specified), and a period in July and August 1979 when the Canadian Bronze smelter was shut down due to excessive levels of lead in air (Krawchuk, 1980). Concentrations of lead in air samples collected in 1979 and 1980 near the Canada Metal and Northwest Smelting facilities exceeded the Manitoba Air Quality Guideline of 5 µg/m^3 (Jones, 1985). Soil lead concentrations collected in the late 1970s in areas in close proximity to the secondary lead smelters were frequently found be ten-fold higher than concentrations that were associated with typical vehicle emissions only. Elevated concentrations of lead were identified in soils within a radius of at least 450-500 m of the Canadian Bronze smelter site located in the Weston neighbourhood. Although a gradient of decreasing soil concentrations with increasing distance from this site was observed, concentrations as high as 1,000 µg/g were still identified near the end of a number of transects extending out from the facility (Wotton, 1979). Elevated concentrations were also identified in the immediate vicinities of the Canada Metal and Northwest Smelting facilities, with relatively low concentrations observed in samples collected at a distance of 300-600 m (Krawchuk, 1980).

Despite these findings, an analysis of lead particulates in air and soil in 1982 to “fingerprint” lead emissions indicated that the major source of lead deposition in the Weston neighbourhood was likely motor vehicle exhaust from Logan Avenue rather than emissions from the smelters (Wotton and Doern, 1983). This was supported by the repeated observation that elevated concentrations were most commonly found in areas of high vehicular traffic (Wotton, 1979; Jones, 1986b; Manitoba Conservation, 2010; Manitoba Sustainable Development, 2019). As a component of the soil investigation conducted by the Province in 1983 (Jones and Wotton, 1983b), sample locations on residential boulevards and schoolyards were selected to represent conditions at various distances from major traffic thoroughfares. Lead concentrations in the sod and upper 5 cm of soil from residential boulevards were highest along major traffic routes such as Osborne Street and Jubilee Avenue in the Riverview neighbourhood, Henderson Highway and Hespeler Avenue in the Elmwood-Henderson Highway neighbourhood, and Portage Avenue in the Wolseley-Portage neighbourhood. Similarly, several school yard samples with the highest soil lead concentrations were collected in close proximity to major traffic routes (*e.g.*, along McPhillips Avenue at Lord Nelson Elementary School, along Sherbrook Street at Sacre-Coeur Elementary School, along Logan Avenue at Dufferin Elementary School, and along Broadway Street at Gordon Bell High School) (Jones and Wotton, 1983). Following the phasing out of leaded gasoline in the late 1980s, the deposition of lead from on-road vehicle exhaust was reduced and eventually eliminated. During the 2007/2008 soil investigation, Manitoba Conservation (2010) noted that “the relationship between traffic flow and lead levels in sod and soil was not as evident”. In addition, given that it was assumed that elevated lead concentrations in soils were associated with atmospheric deposition, it was expected that concentrations would be highest in the near surface layers. However, in locations where samples were collected at both 2.5 and 5 cm depths, concentrations were reported as being very similar (Manitoba Conservation, 2010).

As noted previously, it was also hypothesized that deteriorating lead paint may have contributed to the higher concentrations of lead identified in soils and dust on the Weston Elementary School property (Jones, 1985). Many of the soil samples with the higher lead concentrations collected by the Province in 1983 from numerous additional schools (*i.e.*, Lord Nelson Elementary School, Sacre-Coeur Elementary School, Dufferin Elementary School, and Fort Rouge Elementary School) were suspected to have contained paint chips that may have influenced the results (Jones and Wotton, 1983).

2.1.2 Summary of More Recent Investigations

Many of the investigations conducted in the 1970s and 1980s indicated that concentrations were generally below the guideline of 2,600 µg/g, however, renewed concern over risks related to lead in soils was triggered by the identification of elevated concentrations at the Barber House property in the neighbourhood of North Point Douglas in 2006 (Pinchin, 2006). Manitoba Conservation's review of historical data determined that many of the sites sampled during these older investigations exceeded the current CCME guideline of 140 µg/g for lead in residential soils. Due to lead's affinity to bond with organic matter in soils, it was postulated that these elevated concentrations may still exist in those soils previously sampled (Manitoba Conservation, 2010). As result, the Province conducted a soil sampling program in 2007 to re-sample these locations with the objectives of determining if concentrations had significantly changed over this period and to provide a preliminary assessment of current conditions based on a comparison to the CCME guideline. This included the collection of samples from depths of 2.5 cm, 5 cm, and dust from hard surfaces. The results of this investigation indicated that concentrations of lead in soil, sod, and aggregate materials were lower than those measured in the 1980s. The overall general decrease was attributed to the phasing out of leaded gasoline and the closure of the smelters over this period, while the most dramatic decreases were likely a result of soil and sod replacement (Manitoba Conservation, 2010).

Despite the overall decrease in concentrations, five (5) of the six (6) playgrounds sampled in 2007 contained exceedances of the CCME guideline in sod and/or soil samples from the top 5 cm. No exceedances were identified in areas with aggregate materials, such as sand boxes and areas below swings and play structures. Concentrations of lead had a notable decrease in school yards from the previous sampling event in 1983, with average concentrations decreasing from 1,125 µg/g in 1983 to 82 µg/g in 2007. The Weston Elementary School sports field continued to have elevated levels of lead in the sod and the underlying soil. Although concentrations of lead in sod decreased from an average of 979 µg/g in 1981 to 329 µg/g in 2007, concentrations in the top 5 cm underlying the sod increased from an average of 192 µg/g in 1981 to 463 µg/g in 2007. Concentrations of lead in sod and soil samples collected from residential boulevards in the neighbourhoods of Wolseley/Minto, Riverview/Lord Roberts, and Glenelm/Chalmers were notably lower in 2007 relative to 1983, with a small number of sites containing concentrations above the CCME guideline. However, 17 of 23 samples (74%) collected from North Point Douglas exceeded the guideline. The elevated concentrations observed in boulevards in North Point Douglas were likely attributed to both vehicle emissions at major traffic arteries and airborne dust from local scrap yards. Elevated concentrations in soil have been identified within a radius of approximately 60 m of metal scrap yards, likely the result of airborne dust created from these properties (Manitoba Conservation, 2010).

As a follow-up to the 2007 investigation, the Province conducted a supplemental investigation in 2008 which focused on playgrounds and sports fields in areas in the vicinity of potential historical and current point sources of lead. Overall, concentrations of lead were lower than the CCME guideline of 140 µg/g, with only one exceedance out of 90 samples (Manitoba Conservation, 2010).

In response to public concern, the University of Manitoba, with assistance from the South St. Boniface Residents Association, conducted a soil investigation in fall 2017 that focused exclusively on the neighbourhood of St. Boniface. A total of 174 soil samples were collected at a depth of 0 to 10 cm from commercial and residential properties. This represented the greatest sampling frequency for any of the neighbourhoods sampled to date. The results of this study are proprietary and cannot be presented in this assessment. Overall, less than 15% of samples contained lead concentrations that exceeded the CCME guideline, with less than 5% containing lead concentrations that were more than double the guideline (*i.e.*, 280 µg/g). The average concentration of all samples was well below the CCME guideline of 140 µg/g.

The most recent soil investigation was conducted by the Province in 2018, focusing on locations that were previously sampled during the studies completed by the Province in 2007/2008 and the early 1980s. This investigation was not intended to be an exhaustive study of lead in soil in the City. The objective was to identify any changes in concentrations over time in areas that were included in previous investigations. All samples were collected from a depth of 0 to 7.5 cm, including locations from four (4) residential boulevards (*i.e.*, Wolseley/Minto, Riverview/Lord Roberts, Glenelm/Chalmers, and North Point Douglas), eighteen (18) schools, and thirty-two (32) parks and playgrounds. Exceedances of the CCME guideline were identified at the Weston Elementary School (multiple samples), Westview Park (one sample), and North Point Douglas (multiple samples). Each of these areas were identified as having exceedances in previous investigations (Manitoba Sustainable Development, 2019).

2.1.3 Soil Investigations Selected for Inclusion in a Database

Following a review of the available data, the results of the two (2) most recent soil investigations conducted by the Province, and the investigation conducted by the University of Manitoba, were considered to provide the most applicable soil concentrations for further consideration in the assessment of potential of health risks:

- Manitoba Sustainable Development. 2019. Winnipeg Soil Survey, Fall 2018. Environmental Compliance and Enforcement Branch. January 2019.
- University of Manitoba. 2017. Soil Sampling Results from the St. Boniface Area. 2017 (unpublished).
- Manitoba Conservation. 2010. Sampling Report: Surface Soil Lead Levels in Winnipeg, Manitoba: 2007 and 2008. Report No. 2009-03. Winnipeg, Manitoba.

The selection of these studies was based primarily on the sampling dates, which are reflective of conditions following the phasing out of leaded gasoline and the closure of the secondary lead smelters. In addition, these investigations were conducted with the intention of characterizing lead content in soils at a neighbourhood level rather than site investigations intended to delineate contaminated properties.

The results of these investigations were entered into a database and categorized based on a number of characteristics of the sample, including the neighbourhood in which the sample was collected (Figure 2-2), the sampling date, the sample depth, the nature of material sampled, and a general indicator of the sample location (Table 2-1). This was done to facilitate the identification of potential patterns in soil lead concentrations and to support the assessment of exposure and risks in different areas of the inner City.

Table 2-1 Primary Categories for Winnipeg Soil Sampling Database

Neighbourhood	***Study (sample date)***	***Sample Depth***	***Sample Material***	***Location***
Brooklands Centennial Daniel McIntyre Dufferin Glenelm/Chalmers Lord Selkirk Park North Point Douglas River/Osborne Riverview/Lord Roberts Sargent Park Shaughnessy Heights Shaughnessy Park South Point Douglas St. Boniface Tyndal Park West End Weston Wolseley/Minto	U of M (2017) Manitoba (2007/2008) Manitoba (2017)	2.5 cm 5 cm 0-7.5 cm 0-10 cm Hard Surface Sod	Dust Sand Sod Sod/Soil Soil	Backyard Boulevard Front Yard Garden Playground/Park School Other
n=18	n=3	n=6	n=5	n=7

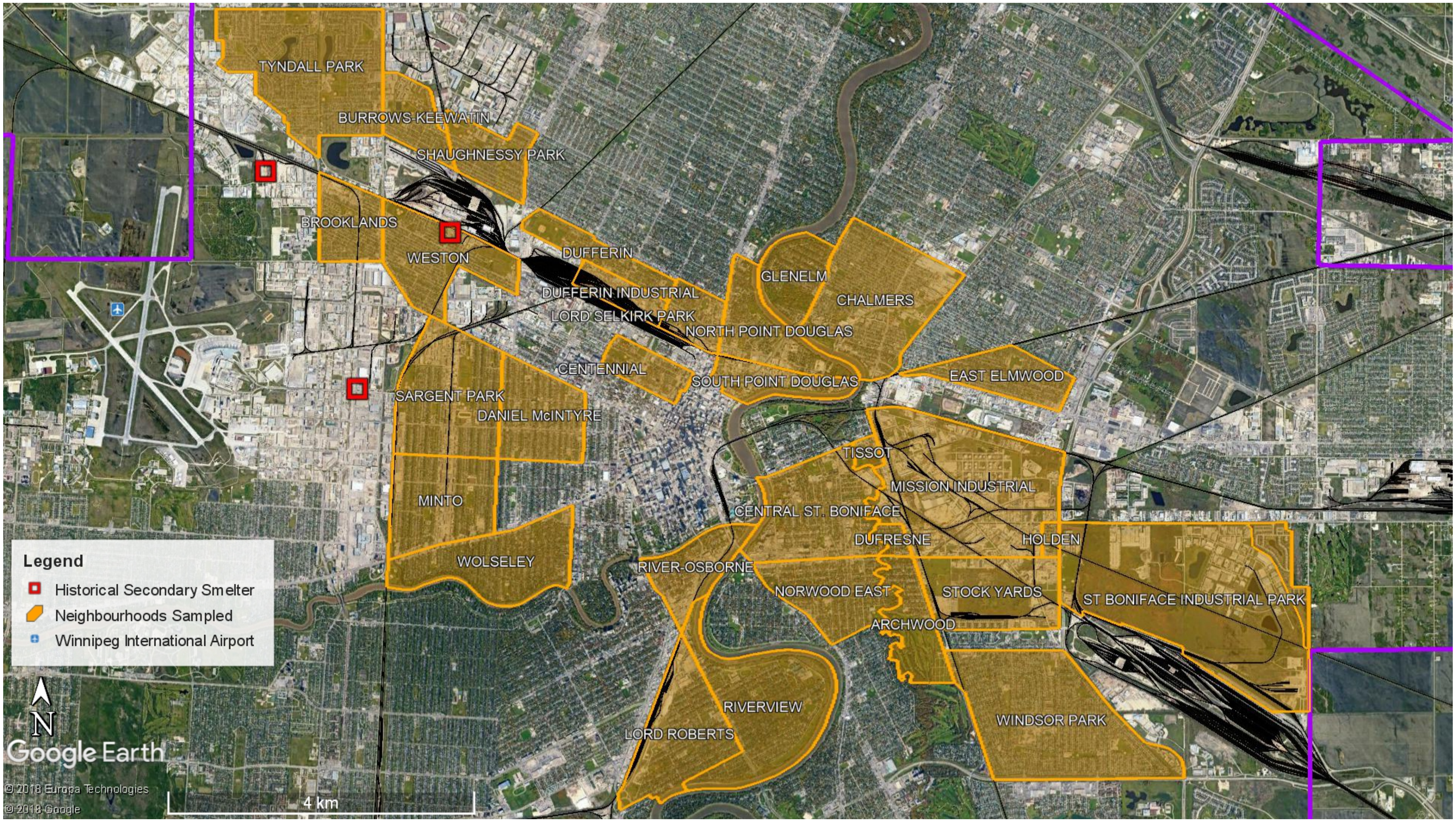


Figure 2-2 **Locations of Neighbourhoods with Soil Sampling Results**

As an initial analysis of the data, only the results of the two most recent investigations (University of Manitoba, 2017 and Manitoba Sustainable Development, 2019) were selected and summarized based on the neighbourhood in which the samples were collected. Table 2-2 presents the total number of samples from both investigations (University of Manitoba, 2017 and Manitoba Sustainable Development, 2019) and identifies the maximum and average (arithmetic mean) concentrations of the compiled data. To provide an indication of the frequency and magnitude of the exceedances, concentrations were compared to both the current CCME guideline (140 µg/g) for lead in residential soils (intended to be protective of human health) and a concentration equal to two-times the guideline of 140 µg/g (280 µg/g). Based on these results, only the neighbourhoods of North Point Douglas, Sargent Park, St. Boniface, and Weston were identified as having potential concerns related to lead in soils, as each of these areas had identified exceedances of the guideline in more than 10% of sampling locations, and each had samples with concentrations of more than double the guideline.

Table 2-2 Maximum and Average Concentrations of Lead in Soil Across Neighbourhoods (Manitoba Sustainable Development, 2019; University of Manitoba, 2017)

Neighbourhood	*Total # of Samples*	*Maximum (µg/g)*	*Average (µg/g)*	*# Samples Above CCME SQG (140 µg/g)*	*# Samples More than 2x CCME SQG (280 µg/g)*
Brooklands	5	95	49.3	0	0
Centennial	4	59.8	43.0	0	0
Daniel McIntyre	4	136	67.1	0	0
Dufferin	2	56.6	55.0	0	0
Glenelm/Chalmers	19	141[a]	61.0	0	0
Lord Selkirk Park	1	97.5	-	0	0
North Point Douglas	26	885	195	11 (42%)	4 (15%)
River/Osborne	1	14.6	-	0	0
Riverview/Lord Roberts	25	125	50.9	0	0
Sargent Park	5	439	139	1 (20%)	1 (20%)
Shaughnessy Heights	2	36.3	28.1	0	0
Shaughnessy Park	3	75.1	52.8	0	0
South Point Douglas	2	141[a]	130	0	0
St. Boniface	177[b]	1,630	88.6	23 (13%)	8 (4.5%)
Tyndal Park	4	33	18.9	0	0
West End	1	54.4	-	0	0
Weston	35	446	174	20 (57%)	4 (11%)
Wolseley/Minto	21	105	38.5	0	0
Overall	**337**	**1,630**	**95.9**	**57 (17%)**	**17 (5%)**

Concentrations highlighted in grey exceed the CCME guideline of 140 µg/g.

a A concentration of 141 µg/g was considered to be equal to the CCME guideline when rounded to 2 significant figures.

b Results include samples collected as part of the studies collected by the University of Manitoba (2017) and Manitoba Sustainable Development (2019).

Given that the number of samples collected for many neighbourhoods within the 2018 Provincial investigation was limited, this same analysis was conducted using the results of the 2007/2008 Provincial investigation combined with the University of Manitoba investigation (Table 2-3). Table 2-3 identifies the maximum and average concentrations of the compiled data provided in University of Manitoba (2017) and Manitoba Conservation (2010). Utilizing these results indicates that approximately 36% of samples (15 of 42) collected from the neighbourhood of Daniel McIntyre exceeded the CCME guideline. No exceedances were identified in this neighbourhood during the 2018 Provincial study. Similarly, multiple exceedances were identified in the neighbourhoods of Dufferin, Glenelm/Chalmers, Riverview/Lord Roberts, Sargent Park, West End, and Wolseley/Minto in 2007/2008 which were not identified in 2018. Based on these results, a number of additional neighbourhoods were identified as having potential concerns related to lead in soils based on the number of samples that exceeded the guideline (Figure 2-3).

Table 2-3 Maximum and Average Concentrations of Lead in Soil by Neighbourhoods (Manitoba Conservation, 2010; University of Manitoba, 2017)

Neighbourhood	*Total # of Samples*	*Maximum (µg/g)*	*Average (µg/g)*	*# Samples Above CCME SQG (140 µg/g)*	*# Samples More than 2x CCME SQG (280 µg/g)*
Brooklands	7	115	43.2	0	0
Centennial	14	307	110	5 (36%)	1 (7.1%)
Daniel McIntyre	42	712	142	15 (36%)	8 (19%)
Dufferin	11	60.3	29	0	0
Glenelm/Chalmers	45	369	71.6	5 (11%)	3 (6.7%)
Lord Selkirk Park	0	-	-	-	-
North Point Douglas	33	2,240	473	26 (79%)	16 (48%)
River/Osborne	10	204	60.4	1 (10%)	0
Riverview/Lord Roberts	47	310	55.9	3 (6.4%)	1 (2.1%)
Sargent Park	13	368	93.8	3 (23%)	2 (15%)
Shaughnessy Heights	1	26.2	-	0	0
Shaughnessy Park	20	176	65.4	1 (5%)	0
South Point Douglas	3	128	53.3	0	0
St. Boniface	197	1,630	87.8	27 (14%)	8 (4.1%)
Tyndal Park	16	125	22.2	0	0
West End	9	212	101	3 (33%)	0
Weston	81	1,130	224	36 (44%)	25 (31%)
Wolseley/Minto	48	290	74.4	6 (13%)	1 (2.1%)
Overall	**597**	**2,240**	**123**	**131 (22%)**	**65 (11%)**

Concentrations highlighted in grey exceed the CCME guideline of 140 µg/g.

[a] Results include samples collected as part of the studies collected by the University of Manitoba (2017) and Manitoba Conservation (2010).

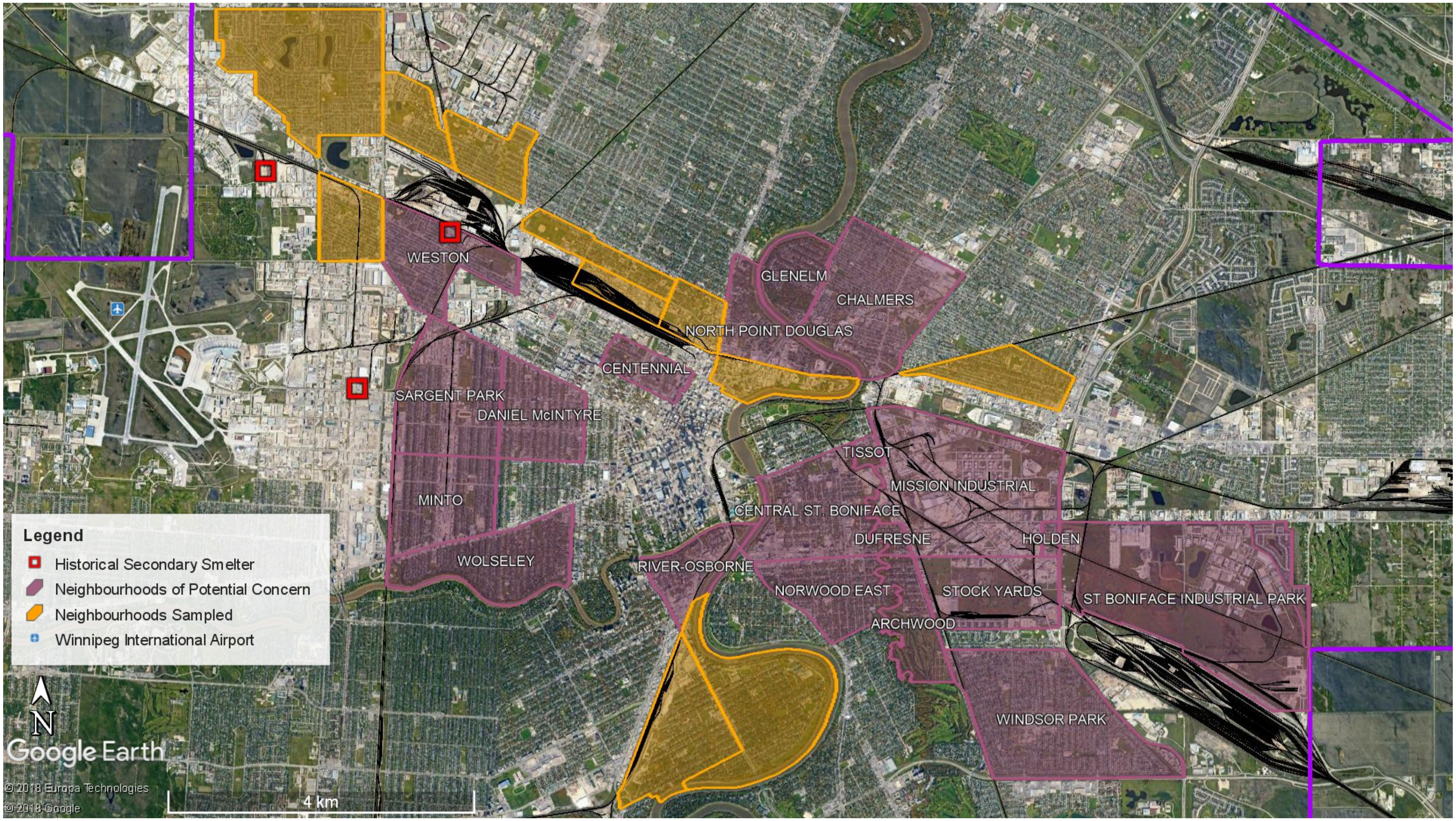


Figure 2-3 Locations of Neighbourhoods with Soil Sampling Results that are Identified as Being of Potential Concern

In addition to the number of samples collected, the two Provincial studies differed in the depths at which the samples were collected. An analysis of lead concentrations at each sample depth was conducted. Given that the sample depths were similar for the 2018 Provincial sampling (0-7.5 cm) and the 2017 University of Manitoba sampling (0-10 cm), results for these depths were combined for comparison to the shallower depths selected by the Province in 2007/2008 (0-2.5 and 0-5 cm) (Table 2-4). This analysis indicated that the highest average concentrations were from 0-5 cm (173 µg/g) and 0-2.5 cm (134 µg/g), which were notably higher than the average concentration from 0-10 cm (95.9 µg/g). The percentage of samples that exceeded the CCME guideline was also higher for samples collected at 0-5 cm (34%) and 0-2.5 cm (21%) relative to samples collected at 0-10 cm (17%).

The primary purpose of the investigation conducted by the Province was to characterize soil lead concentrations and the change in concentrations over time rather than to support the preparation of an HHRA. The influence of deposited lead particles on soil concentrations is typically limited to depths of less than 5 cm due to binding of lead within the soil matrix. Surface soils containing lead pose the greatest hazard to children, as they may contaminate hands and be ingested through hand-to mouth activity. Surface soils may also stick to footwear, toys, pets and contribute to household exposure levels (NZ MOH, 2012). The CCME (2016) has recommended that when assessing direct contact pathways in HHRAs, the most relevant soil depth tends to be less than 5 cm. This is consistent with the US EPA (2003) Superfund program which has developed a handbook for evaluating lead contamination at residential sites. The recommended sampling depth for use in HHRAs is 0 to 1 inch (or 0 to 2.54 cm) as this best represents current exposure to contaminants.

Table 2-4 Lead Concentrations by Sample Depth Based on the Results of the University of Manitoba (2017), Manitoba Sustainable Development (2019), and Manitoba Conservation (2010) Soil Investigations

Sample Depth (cm)	*# Samples*	*Maximum (µg/g)*	*Average (µg/g)*	*# Samples Above CCME SQG (140 µg/g)*	*# Samples More than 2x CCME SQG (280 µg/g)*
0-2.5[a]	56	1,790	134	12 (21%)	5 (8.9%)
0-5	176	2,240	173	59 (34%)	36 (20%)
0-7.5 and 0-10	337	1,630	95.9	57 (17%)	17 (5.0%)
Sod	156	907	107	32 (21%)	14 (9.0%)
Hard Surface	35	307	85.6	5 (14%)	2 (5.7%)

Concentrations highlighted in grey exceed the CCME guideline of 140 µg/g.
[a] Results include samples labelled as Sand, Soil, and Sod/Soil.

The results of these analyses indicate that the data provided in the two most recent investigations alone (*i.e.*, Manitoba Sustainable Development (2019) and University of Manitoba (2017)) may not be adequate to assess potential exposure and risks to residents throughout the neighbourhoods of the inner city of Winnipeg. The greater number of samples and the shallower sample depths provided in the earlier Provincial investigation (Manitoba Conservation, 2010) should also be considered as they improve the overall understanding of the distribution of lead content in soils.

2.1.4 Preliminary Screening-Level Assessment of Risks

Based on the assessment of historical data presented in Section 2.1.3, there are a number of neighbourhoods which have been identified as areas of potential concern. Specifically, several neighbourhoods were identified during the data review as having 10% or more of soil samples with lead concentrations above the applicable CCME guideline of 140 µg/g for residential soils:

- Centennial
- Daniel McIntyre
- Glenelm/Chalmers
- North Point Douglas
- River/Osborne
- Sargent Park
- St. Boniface
- West End
- Weston
- Wolseley/Minto

A more in-depth discussion of the potential health risks associated with the elevated lead concentration in soils will be discussed in Task 4.

It is important to note that the identification of these neighbourhoods as being of potential concern is based on a limited number of samples which may not accurately characterize soil lead concentrations throughout these areas. Additionally, other neighbourhoods may also contain lead concentrations occurring at a frequency and magnitude that represent a potential concern which have not been identified by the available data. Section 2.1.5 further describes the uncertainties and data gaps associated with the existing information characterizing soil lead concentrations in Winnipeg.

2.1.5 Summary of Uncertainties and Data Gaps

Uncertainties associated with the available data describing lead content in soils throughout the inner City are primarily related to three (3) factors: 1) the date at which the samples were collected, 2) the sample depth, and 3) the sampling frequency. The investigations conducted by the Province involved sampling on public properties, whereas the University of Manitoba focused primarily on residential properties. Samples collected as part of the studies conducted by the Province in 2018 and the University in 2017 involved the collection of composite samples consisting of 10 individual cores. The 2007/2008 Provincial study utilized a combination of composite samples consisting of 3 to 20 cores, and discrete samples for hard surfaces.

Three (3) samples were collected from the neighbourhood of St. Boniface as part of the 2018 Provincial investigation. Each of these samples contained concentrations of lead (18, 19.3, and 64 µg/g) that were below the CCME guideline (140 µg/g), with an average of 33.8 µg/g. These results would not have identified a potential concern in this neighbourhood. Results of the University of Manitoba study in which 174 samples were collected from St. Boniface indicated that 13% of samples (23 of 174 samples) contained concentrations that exceeded 140 µg/g. Samples collected by Manitoba Conservation in 2007/2008 in which 23 samples were collected from sod, soil, sand, or hard surfaces in St. Boniface identified four (4) soil or sod samples with concentrations that exceeded 140 µg/g, with an overall average of 74.8 µg/g. This demonstrates the variability in results across studies. As there is a low sampling frequency in the discussed studies, greater sampling frequency may have provided additional clarification in understanding which neighbourhoods are of potential concern due to soil lead concentrations.

Given that emissions from vehicles has been identified as a dominant source of lead in soils, there is the potential that numerous additional neighbourhoods throughout the city that have not been sampled may have experienced a similar level of deposition due to proximity to roadways and also contain soil lead concentrations in excess of the CCME guideline. There may also be areas of neighbourhoods that have been included in the investigations that contain higher concentrations than the neighbourhood as a whole. Notable efforts were taken to remove impacted soils and debris from the Weston Elementary School on a number of occasions due to the high lead concentrations. In addition, impacted soils from numerous residences and boulevards were removed in the Weston neighbourhood in the early 1980s (Jones and Wotton, 1982; 1983a). The selection of areas for remediation was based on the identification of soils with concentrations of lead in excess of 2,600 µg/g which was the action criterion in effect at the time. Therefore, concentrations of lead on public and residential properties may still be significantly elevated relative to the current CCME guideline.

Soil samples were collected at depths of 0 to 10 cm during the 2017 St. Boniface investigation, and from 0 to 7.5 cm during the 2018 Provincial Investigation. This differed from the 1980 Provincial study in which samples were collected from the top 2 cm of soil for surface samples and from a depth of 2 to 4 cm for subsurface samples (Krawchuk, 1980). It was also inconsistent with the 2007/2008 Provincial investigation where samples were collected at depths of 0-2.5 cm and 0-5 cm (Manitoba Conservation, 2010). This creates uncertainty when comparing results across the investigations to identify trends in concentrations over time. Given that the 2017 and 2018 samples were collected at greater depths than in previous studies, the noted decreasing trend in concentrations may have been influenced by a diluting effect by including soils found at depths that may have not been exposed to atmospheric deposition. Given the limited leaching potential of lead, soils found at depths of 7.5 to 10 cm may have resulted in lower average concentrations across the sampling profile relative to samples that were limited to the near surface. In addition, the general population may not encounter soils found at these depths on a frequent and prolonged basis. Therefore, the results of the 2017 and 2018 soil investigations may not accurately represent concentrations of lead that receptors are exposed to during typical daily activities.

As noted by Manitoba Conservation (2010), although many of the sources of lead emissions are no longer present, the affinity for lead to bind to organic matter in soil will allow lead to persist in surface layers. As a result, the elevated concentrations of lead that were identified in earlier soil investigations are likely to continue to be present in soils that have not be removed or amended since the early 1990s.

2.2 Detailed Review of Available Reports and Data

The following sections provide a more detailed review of individual studies that were conducted within the City of Winnipeg to address concerns related to lead content and exposure. These reports are generally presented in chronological order.

2.2.1 Occupational Medical Services. 1976. Lead in Blood of Two Elementary School Children in Winnipeg, 1976.

In 1975, elevated BLLs were identified in workers at a Winnipeg foundry that resulted in some individuals requiring medical intervention. This led to concerns over the health of residents in the surrounding neighbourhood that may have exposure to lead from atmospheric releases from this facility, from particulates brought home on clothes from foundry workers, and from exhaust emissions from heavy vehicular traffic running through the neighbourhood. To assess potential exposure to lead, the Occupational Health Services of the Manitoba Department of Health and Social Development conducted a study in 1976 which involved the collection of blood samples from students from the Weston Elementary School. A second school, Lord Nelson School, was identified as a suitable control group given that it was located in a neighbourhood without a point source of lead emissions but was located on a road with a similar level of heavy vehicular traffic as the Weston school.

Methodology

Blood samples were collected from 295 students at Weston Elementary School and from 421 students from Lord Nelson School. Permission to conduct the study was obtained from the No. 1 School Division and consent was granted by the parents of the students. Samples were collected from students at Weston School on April 15th and 19th, and from students at Lord Nelson on May 3rd- 5th, 1976. Repeat blood samples were collected from twenty-nine (29) students at Weston School on June 10th and from twenty (20) students from Lord Nelson on June 11th for those who showed higher levels or unusual results which may have been attributed to accidental specimen contamination during the initial testing.

Three (3) tests were performed on the blood samples. Blood lead analysis was performed on all samples collected, while approximately ¼ of all samples were also analyzed for erythrocytic delta-aminolevulinic acid dehydratase (ALAD) and free erythrocyte porphyrin (FEP).

Results

The reported mean (assumed to be arithmetic mean) BLLs for students from Weston and Lord Nelson Elementary Schools were 24.1 and 19.6 µg/dL, respectively. A summary of the results is provided in Table 2-5.

Table 2-5	Blood Analysis Results for Students from Weston and Lord Nelson Elementary Schools (1976)								
Location	**Blood Lead (µg/dL)**			**ALAD (units)**			**FEP (µg/dL RBC)**		
	$\bar{X}$ (n)	**S.D.**	**$\bar{X}$ ± 2 S.D**	**$\bar{X}$ (n)**	**S.D.**	**$\bar{X}$ ± 2 S.D**	**$\bar{X}$ (n)**	**S.D.**	**$\bar{X}$ ± 2 S.D**
Lord Nelson	19.6 (421)	8.1	0- 35.8	789 (105)	185	419- 1159	5.7 (70)	2.2	1.3- 10.1
Weston	24.1 (295)	7.5	0- 39.1	725 (81)	237	251- 1199	7.7 (52)	2.6	2.5- 12.9
Normal (literature)	-	-	0- 40	-	-	300- 1020	-	-	1.0- 10.0

$\bar{X}$ Assumed to represent the arithmetic mean.
n Represents the number of samples.

Limitations and Uncertainties

Limited information was provided within the report to describe the study methodologies (*e.g.*, venous or capillary blood sampling), the characteristics of the sampled population (*e.g.*, ages of the students), or the interpretation of the results. It is unclear if the BLL results were identified as being elevated or within a normal range relative to the general population. There is no indication that a survey or questionnaire was conducted for participating students to identify any additional potential sources of lead exposure that may differ from the general population. Due to the age of these results, they are not reflective of current lead exposure opportunities given that lead content in fuel, paint, plumbing, and consumer products have been considerably reduced since the completion of this study. The contribution of these sources to total exposure relative to lead content in soil, dust, and air cannot be distinguished.

2.2.2 Wotton, D.L. 1979. A Survey of Lead Accumulation in Tree Foliage and Surface Soil of the Winnipeg Area. Manitoba Department of Mines, Natural Resources and Environment. Environmental Research and Development Branch. Report 79-4.

In response to concern over the identification of elevated BLLs in school children living in high traffic areas in Winnipeg, a study was conducted in 1979 by the Air Pollution Control Branch of the Environmental Management Division along with the Environmental Research and Development Branch. A survey of urban tree foliage and surface soil was conducted in areas within Winnipeg with varying traffic patterns, in areas adjacent to lead smelters, and in the immediate area of Lord Nelson and Weston Elementary Schools.

Methodology

The survey focused on two principal sources of lead emissions: non-industrial and industrial. Five (5) areas were surveyed in consideration of the non-industrial sources including a National Air Pollution Surveillance (NAPS) station at Scotia Street and Jefferson Avenue (low traffic volume); a NAPS station at Portage Avenue (high traffic volume); Weston Park, Logan Avenue at Lock Street (medium traffic volume), and two schools (Lord Nelson and Weston Elementary Schools). In consideration of industrial emission sources, areas adjacent to three (3) major secondary lead smelting facilities were surveyed (*i.e.*, Canadian Bronze at 15 Bury Street, Canada Metal at 1221 St. James Street, and Northwest Smelting and Refining at 2185 Logan Avenue). Tree foliage was selected for analysis of lead content from natural or well-established street plantings at each sampling location. Samples were collected in early July and in late August. Selected trees were identified, and a random composite sample was taken from the crown. At each sampling site, a composite surface soil sample, in close proximity to the tree selected for foliage sampling, was collected by combining five (5) soil cores (to a depth of 3 cm).

Results

Notable variability in lead absorption and accumulation between tree species was noted. The results indicated that lead accumulation due to urban traffic resulted in concentrations ranging from 17.6 to 43.4 µg/g in foliage, and 132.5 to 1,085 µg/g in surface soils for areas of low and high traffic, respectively. Lead concentrations at both schools were noted to be high and a gradient of decreasing concentration was found as distance increased from major emission sources. Lead concentrations in proximity to secondary lead smelters were frequently 10-fold greater than concentrations found to accumulate from normal vehicle emissions. Soil concentrations at the industrial sites exceeded the applicable guideline of the time (*i.e.*, 2,600 µg/g) in several instances. The report noted that substantial lead accumulation had occurred in foliage at these sites and that it was anticipated that the same degree of accumulation could occur in plant tissues and soils found in vegetable gardens.

Limitations and Uncertainties

The report noted that the survey included multiple species for foliage sampling which was dependent on the species availability on each of the sites. Variances were identified between species which may have affected the interpretation of results between sites.

2.2.3 Krawchuk, B.P. 1980. Thesis: A Survey of Soil Lead Levels in the City of Winnipeg. Submitted to the Faulty of Graduate Studies in Partial Fulfilment of the Requirements for the Degree of Master of Science. Department of Chemistry, University of Winnipeg. August 1980.

The study was undertaken to characterize lead contamination in the City of Winnipeg, to identify the potential sources of contamination, and to determine if there is a pattern of distribution associated with the lead pollution. Sites selected for sampling included residential and industrial areas with both high and low traffic arteries. An initial survey and a monitoring survey were conducted in 1978 and 1979, respectively. A snow survey was also conducted.

Methodology

The initial survey was conducted in September 1978 during which one hundred and sixteen (116) locations were sampled from one hundred and seven (107) different sites within the city. Two hundred and twenty-four (224) samples of surface and subsurface soil and vegetation were collected. At one hundred and sixteen (116) locations, surface soil samples were collected from a depth of 0 to 2 cm, and at ninety-four (94) locations, subsurface samples were collected from a depth of 2 to 4 cm. A sample of 5 to 10 g of vegetation was collected at nineteen (19) sites.

From the initial survey, seventy-five (75) sites were selected for the monitoring survey. Surface soil from the top 1 to 2 cm was collected. Two (2) snow surveys were conducted in February 1979. The first sampled thirty-five (35) sites by Red River on the east and Portage Avenue on the north, and the second survey was carried out in the Weston area with thirty (30) sites sampled. Fresh snow was gathered by major arteries from the top 1 to 2 cm by a scoop-and-pack method.

Results

The average lead concentration for all sites was 750 µg/g ± 1,300 µg/g, ranging between 30 µg/g and 12,960 µg/g. The maximum concentration (12,960 µg/g) was detected at a secondary lead smelter site. The report indicated that the removal of this maximum concentration resulted in an average of 640 µg/g ± 520, and a range between 30 µg/g and 2,920 µg/g. The subsurface soil sample concentrations ranged from 0 to 2,220 µg/g, with an average of 410 ± 450 µg/g. The concentrations in vegetation ranged from 0 to 470 µg/g, with an average of 120 ± 139 µg/g.

The sample sites near the secondary lead smelters (denoted in the report as #51, #52 and #60) were observed to have higher lead levels relative to other sites. Specifically, site #51 at Wellington Avenue by Canada Metals had a concentration of 2,920 µg/g in surface soil, site #52 at Wellington Avenue by Canada Metals had a concentration of 12,960 µg/g in surface soil, and site #60 at Ryan Road east of North West Smelting had a concentration of 1,520 µg/g in surface soil. The report notes that a background concentration for lead in soil for the area is 30 µg/g based on site #1 which is an undeveloped area in a natural clearing located over 300 m from the nearest roads.

From the monitoring survey, a seasonal variation was noted where soil lead concentrations increased in the fall, reduced in the spring, and increased in the summer. This was hypothesized to be due to the leaching of the soil lead by salt during spring thaw. The averages in fall, spring, summer and fall again were noted to be 680 ± 570 µg/g, 410 ± 600 µg/g, 560 ± 530 µg/g, and 850 ± 750 µg/g. The report found that the 15 sites sampled in the Weston area had an average soil lead concentration of 725 ± 745 µg/g with a range of 90 to 2,820 µg/g. The results from the monitoring survey indicated that the pollution control devices in the three smelter plants were not removing all of the lead from the air or were not working at all in some cases.

The report also presents data for tin and antimony. Tin and antimony were selected for analysis from the x-ray fluorescence data to investigate correlations between lead and other metals present in the soil sample. No correlations between tin or antimony and lead levels were observed.

Further soil testing and a more comprehensive blood-lead study was recommended by the report.

2.2.4 Wotton, D.L. and F.E. Doern. 1983. Lead Particulate Analysis in Air and Soil of the City of Winnipeg 1982. Manitoba Environmental Management Division, Environmental Services Branch, Terrestrial Standards and Studies. Report 83-3. April 1983.

The study was completed by the Environmental Management Division of the Manitoba Department of Environment and Workplace Safety and Health in partnership with Atomic Energy of Canada Ltd. (AECL) and the Canadian Bronze Company. The objective of the study was to develop a better understanding of the forms of lead occurring on particles originating from different sources throughout the city. The study was noted as being partially funded by the Canadian Bronze company. The study was completed as follow-up to remedial activities completed in 1981 and 1982.

Methodology

The method was developed by AECL using scanning electron microscopy (SEM)/energy dispersive x-ray spectrometry to fingerprint lead emissions by source. Twenty (20) samples were collected from eighteen (18) locations throughout Winnipeg including the three (3) secondary lead smelters with emphasis on the Weston area, NAPS sites, Weston Elementary School, and three other schools in north-central Winnipeg (Lord Nelson School, Dufferin School, Tyndall Park School). Follow-up surveys of soil were taken at Weston Elementary School in the north yard adjacent to Logan Avenue where remediation was conducted.

Results

The highest rates of lead accumulation were observed to be alongside major traffic arteries, notably near Lord Nelson School, Dufferin School, and Weston School. The study indicates that SEM/energy dispersive x-ray spectrometry is a useful technique to fingerprint lead smelter emissions.

The study concludes that the major source of lead was motor vehicle exhaust rather than smelter emissions. The report states that "*Secondary smelters may be significant contributors to very localized high lead concentrations, and although elevated concentrations of lead were found in the Weston school yard, one year after clean-up, the major source is believed to be the exhaust of motor vehicle traffic*".

Initial microanalysis identified a close association between lead and zinc in samples from the Canadian Bronze smelter stack. Lead and zinc were found at elevated concentrations and in close association in soils at sites closest to the Canadian Bronze facility. Lead and zinc were not found in association with soil samples at other schools or smelters in north-central Winnipeg.

The report suggested that other schools in Winnipeg may also have high lead levels due to their close proximity to major traffic arteries. The report also notes that very localized, high soil lead concentrations, for example at 2126 Logan near Smelter B and 1476 Wellington near Smelter C, suggest that the smelters may be significant contributors.

2.2.5 Kucera, E. 1983. Lead Distribution in Winnipeg as Reflected by City Area Dogs. Manitoba Department of Environment and Workplace Safety and Health, Environmental Management Division, Terrestrial Standards and Studies Section. Report 83-10.

As a follow-up to elevated BLLs being identified in children and secondary smelter workers, a study of lead in the blood of dogs was conducted in Winnipeg in 1981. Normal and toxic concentrations of lead in the blood of children and dogs were considered to be similar, therefore, dogs were used as biomonitors of lead exposure.

Methodology

Blood samples of dogs from participating veterinary clinics from across Winnipeg were collected in August 1981. The age and breed of the dog, along with its residential address to the nearest block, was recorded. Four hundred and eighty (480) blood samples were analyzed for lead. The report noted that the individual upper limit of 35 µg lead/100 mL (equal to 35 µg/dL) blood is the same for dogs and children.

Results

The BLLs ranged between 0.04 and 28.35 µg/dL. The second highest concentration was 15.45 µg/dL. It was determined that 95% of dogs sampled had BLLs less than 8 µg/dL which was considered to be within the normal range. Air lead concentrations ranged between 0.18 and 0.38 µg/m^3.

The results showed that dogs from areas with heavy traffic were found to have the highest BLLs, with blood lead proportionally increasing per km to traffic areas. The findings indicated that although traffic significantly contributed to lead exposure, BLLs found in dogs did not exceed recommended medical limits.

Limitations and Uncertainties

A correlation between air lead concentrations at air monitoring stations and BLLs of dogs nearby was not identified. The sample size was not considered to be large enough for a proper comparison given the variability. The report also notes that it is possible that dogs “sample” a different component of the lead emissions then the air monitors.

The study noted that a disadvantage of using dogs was that some areas may not be adequately covered since this study depends on the dog population in a given neighbourhood. Additionally, a large sample size would be required to obtain credible results.

2.2.6 Jones, D.C. and D.L. Wotton. 1983a. Lead Program Report. Boulevard Sod/Soil Removal and Replacement in the Weston Area of Winnipeg. 1983. Manitoba Department of Environment and Workplace Safety and Health, Environmental Management Division, Terrestrial Standards and Studies Section. Report 83-16.

In 1981, an intensive soil survey was conducted in the vicinity of the Canadian Bronze smelter located at 15 Bury Street to identify levels of lead in soil. The 1981 survey identified exceedances of the applicable guidelines of the time (2,600 µg/g) on thirty-one (31) private properties, on the picnic site of the smelter facility, and on twenty-seven (27) 15-meter sections of boulevard in the Weston area. As such, the Environmental Management Division recommended the removal and replacement of soil and sod from these impacted sites. The removal and replacement took place in June 1982 at twenty-six (26) residential properties and at the Canadian Bronze picnic site. Work on the impacted boulevard began on June 23, 1983 by Lach Brothers Landscaping Limited of Winnipeg.

Methodology

Sections of impacted land in the Weston neighbourhood included boulevard lands along Bury Street, Quelch Street, Vine Street, Irysh Avenue, Catherine Avenue, Whyte Avenue, Gallagher Avenue, and Logan Avenue.

The acceptable background level for lead in soil was selected to not exceed 200 µg/g of lead for both sod and soil. To ensure that the replacement material was less than 200 µg/g, six (6) samples were taken from designated piles and submitted for analysis. As indicated in the remediation program, the soil and sod had to be removed to a minimum depth of 15 cm at the boulevard sites.

Results

Concentrations of lead in samples analyzed from the replacement material were all below 50 µg/g. Lead concentrations pre-and post- remediation were reported. The highest initial concentration pre-remediation was 6,800 µg/g in a sample located along Irysh Avenue, with the majority of the samples over 3,000 µg/g. Following replacement, concentrations were reduced to 150 µg/g or less.

2.2.7 Jones, D.C. and D.L. Wotton. 1983b. A Survey of Lead in Soil from Seven Schools and Three Residential Areas of Winnipeg. 1983. Manitoba Department of Environment and Workplace Safety and Health, Environmental Management Division, Terrestrial Standards and Studies. Report 83-15.

As a follow up to the report "Wotton, D.L. and F.E. Doern. 1983. *Lead Particulate Analysis in Air and Soil of the City of Winnipeg 1982*", a second clean-up was carried out in the north yard of the Weston school on June 4th, 1983. Additionally, lead was measured in soil and particulate debris from paved playgrounds at seven (7) additional Winnipeg schools, and in sod and soil within three (3) Winnipeg residential areas.

Methodology

The following seven (7) schools were included in the survey:

- Lord Nelson Elementary School
- Dufferin Elementary School
- Sacre-Coeur Elementary School No. 2
- Gordon Bell High School
- Fort Rouge Elementary School
- Archwood Elementary School
- Norberry Secondary School

A sixteen (16)-site sampling network was employed for each school, and sampling was conducted during the first week of August. Samples of soil, dust, or particulate debris were collected using a plastic spoon and whisk.

The residential areas included in the survey were Elmwood, Riverview, and Wolseley. Sampling was conducted in July and late August. A series of ten (10) sample cores were taken at each collection site. Each series of ten (10) cores of both sod and soil were bulked separately. The soil cores were collected to a depth of 5 cm using a 2 cm diameter Oakfield corer. Sod and soil samples were collected at the Riverview to Osborne Street area (n=30), the Elmwood to Henderson Highway area (n=29), and at the Wolseley to Portage Avenue area (n=26).

Results

Schools

Samples with elevated soil lead concentrations were hypothesized to be impacted by paint chips or traffic emissions due to sampling locations. Soil lead concentrations at each school ranged as follows:

- Lord Nelson Elementary School: 205 to 2,400 µg/g.
- Dufferin Elementary School: 555 to 1,200 µg/g.
- Sacre-Coeur Elementary School No. 2: 125 to 1,100 µg/g.
- Gordon Bell High School: 45 to 1,900 µg/g.
- Fort Rouge Elementary School: 630 to 1,850 µg/g.
- Archwood Elementary School: 70 to 670 µg/g.
- Norberry Secondary School: 80 to 910 µg/g.

Residential

Soil lead concentrations in residential areas ranged as follows:

- Riverview-Osborne Street area: 36 to 1,044 µg/g.
- Elmwood to Henderson Highway area: 10 to 1,600 µg/g.
- Wolseley to Portage Avenue area: 30 to 1,400 µg/g.

2.2.8 Jones, D.C. and D.L. Wotton. 1982. Lead Program Report, Soil Sod Removal and Replacement in the Weston Area of Winnipeg, 1982. Terrestrial Standards and Studies, Environmental Services Branch, Environmental Management Division. Report 82-3.

In 1981, an intensive soil and sod survey was conducted in the vicinity of the Canadian Bronze smelter in the residential area of Weston. The 1981 survey identified exceedances of the applicable guidelines of the time (2,600 µg/g) on thirty-one (31) private properties, on 450 m of boulevard, and on the picnic site of the smelter facility. As such, the Environmental Management Division recommended the removal and replacement of soil and sod from these impacted sites. A contract was awarded to McEwen Brothers Landscaping Co. and the residential removal/replacement program started on June 21 and was completed June 20, 1982. The Canadian Bronze picnic site was independently contracted to McEwen brothers and the removal/replacement on this site was completed on July 22, 1982.

Methodology

Of the thirty-one (31) residences, five (5) declined to participate in the replacement program. Following the replacement of impacted materials, a series of ten (10) sampling cores from each designated yard location was collected. Each set of ten (10) cores were collected to a depth of

5 cm. The acceptable background level for lead in soil was selected as to not exceed 200 µg/g of lead for both sod and soil.

Results

The report concluded that lead in soils from the Weston area are associated with historical accumulation from smelter emissions, vehicular exhaust, and/or leaded paint.

2.2.9 *Jones, D.C. 1985. A Synopsis of the Lead Program at Weston Elementary School in the City of Winnipeg. Terrestrial Standards and Studies, Environmental Management Division, Manitoba Environment and Workplace Health and Safety. Report 85-3.*

The report provides background information on the history of lead issues at Weston Elementary School and an overview of cleanup work completed in 1981 and 1983. The synopsis report referenced a number of historical reports (Jones and Wotton, 1983a,b; Wotton, 1979; Wotton, 1980; Bezak, 1979; Wotton 1981a; Wotton, 1981b; Wotton, 1981c; Wotton and Bezak, 1980; Wotton and Doern, 1983). In addition, a description of the monitoring/investigation conducted by the Environmental Management Division was provided. Remediation was noted to consist of dry vacuuming and soil loosening.

Summary

Elevated BLLs were found in children at the Weston and Lord Nelson Elementary Schools in 1976 and 1979. Elevated BLLs in workers was noted but no further details were provided. Emissions from the Canadian Bronze facility located in close proximity to Weston school was initially suspected as being the source, as well as two other secondary smelters in the area. However, soil and vegetation studies completed in the 1980s, along with vegetation/foliage data, was noted as being suggestive of traffic thoroughfares being associated with elevated concentrations in soils In Winnipeg.

Two (2) 1981 studies were conducted to evaluate the extent of lead contamination in the area surrounding the Canadian Bronze facility. In the soil survey conducted in April 1981, sixty-eight (68) residences, 1,400 m of boulevards, and the playgrounds of Weston Elementary School were identified as areas needing for further study. The soil survey conducted in July 1981 recommended that particulate debris with lead levels greater than 2,600 µg/g be removed from the paved play area on the north side of Weston school. Remediation occurred between 1981 and 1983. The initial investigation in 1981 indicated that the paved play area at Weston School had an average concentration of 4,850 µg/g, and remediation was carried out in the affected area. Following the initial remediation, it was indicated that lead levels were above the guideline of 2,600 µg/g in newly accumulated migrant dust, resulting in the completion of a second remediation at the Weston School.

A joint initiative by the Canadian Bronze Company and the Atomic Energy of Canada at Pinawa investigated lead particulate ‘fingerprints’ for impacted sites in Winnipeg. The report “*Lead Particulate Analysis in Air and Soil of the City of Winnipeg*” suggested that traffic emissions along Logan Ave was the primary contributor to lead concentrations at the Weston school. Paint chips containing lead were also hypothesized as a possible source of contamination.

Air data that was collected from a sampler on the roof of Weston school in 1984 was found to be within the Manitoba Air Quality Guideline of 5 µg/m^3 for lead at the time. Air concentrations indicated that the 24-hour mean ranged between 0.59 µg/m^3 and 1.13 µg/m^3 over a seven (7) month period.

In 1984, remedial action was taken at the Weston school by removing lead paint on outdoor walls and by the replacement of soil and sod. A commitment to additional monitoring of lead-in-air and sod and soil was made for the Weston school. To study the relationship between exhaust emission and lead levels in soils, further investigation was recommended.

2.2.10 Jones, D.C. 1986b. A survey of lead-in soil concentrations from seven rural communities in Manitoba, 1984. Department of Environment and Workplace Safety and Health, Environmental Management Division, Terrestrial Standards and Studies Section. Report No. 86-2.

As a follow up to the report "Wotton, D.L. and F.E. Doern. 1983. *Lead Particulate Analysis in Air and Soil of the City of Winnipeg 1982*", the Province initiated a plan to expand monitoring in rural communities of Manitoba. Initially, Thompson and Flin Flon-Channing were surveyed. In 1984, seven (7) additional rural centres were evaluated for lead in soil. The communities included in the study were Selkirk, Steinbach, Portage la Prairie, Brandon, Dauphin, Swan River, and The Pas. The report presents the results for the seven (7) communities evaluated in 1984.

Methodology

A series of ten (10) sample cores were taken at each site to a depth of 5 cm. Each series of ten (10) cores for both sod and soil were bulked and stored separately. The sample sites were located adjacent to, and at varying distances from, major traffic thoroughfares.

Results

Concentrations of lead in sod and soil ranged as follows:

- Selkirk: 31 to 568 µg/g.
- Steinbach: 31 to 338 µg/g.
- Portage la Prairie: 57 to 428 µg/g.
- Brandon: 10 to 910 µg/g.
- Dauphin: 53 to 504 µg/g.
- Swan River: 15 to 226 µg/g.
- The Pas: 21 to 357 µg/g.

The results indicated that there was no consistent relationship between proximity to roadways and lead soil concentrations. This was hypothesized to be due to different traffic patterns in smaller communities. It was noted that there was a slight trend of increased lead concentrations at sites adjacent to major traffic thoroughfares.

The report concluded that measured soil lead concentrations were within the range of background concentrations for other Manitoba communities, and were less than 2,600 µg/g (the guideline of the time).

2.2.11 Jones, D.C. 1986a. Manitoba Environmental Management Services Branch, Department of Environment and Workplace Safety and Health. A Survey of Lead-In-Soil Concentrations at Seven Tot Lots in the City of Winnipeg. Report 86-3.

In 1984, sod and soil samples were collected by the Environmental Management Division (Terrestrial Standards and Studies Section) of the Manitoba Department of Environment and Workplace Safety and Health from seven (7) tot lots that were adjacent to major traffic roads.

Methodology

Seven (7) Winnipeg tot lots were selected for sampling. These included the following:

- Central Park - (Cumberland Ave. at Edmonton St.)
- Home Playground - (Sargent Ave. at Horne St.)
- Notre Dame Park - (Notre Dame Ave. at McGee St.)
- Maryland Tot Lot - (Maryland St. at Wellington Ave.)
- Spence Tot Lot - (Cumberland Ave. at Spence St.)
- Archibald Tot Lot - (Archibald Ave. at Provencher Blvd.)
- Hespeler Park - (Hespeler Ave. at Glenwood Cr.)

In sodded areas, a 2 cm soil corer was used to collect the sod and the upper 5 cm of soil. A series of ten (10) sample cores were taken at each collection site. Each series of ten (10) cores for the sod and soil were bulked separately. For areas where the cover was sand, gravel, or exposed organic soil, a scoop was used to collect a composite sample.

Results

Results indicated that lead concentrations in sod and soil samples were below the acceptable limit of 2,600 µg/g of the time. Concentrations of lead ranged between 15 µg/g and 740 µg/g. It was noted that the tot lots immediately adjacent to high traffic volume thoroughfares were found to have the highest lead concentrations.

Concentrations of lead in sod and soil ranged as follows:

- Central Park: 50 to 680 µg/g.
- Home Playground: 30 to 320 µg/g.
- Notre Dame Park: 30 to 165 µg/g.
- Maryland Tot Lot: 30 to 345 µg/g.
- Spence Tot Lot: 40 to 680 µg/g.
- Archibald Tot Lot: 30 to 395 µg/g.
- Hespeler Park: 15 to 330 µg/g.

The report notes that the soil lead concentrations were consistently lower in the sand box, slide, and swing play areas where sand and gravel were present. Concentrations of lead in sod were consistently higher than in sand.

2.2.12 Manitoba Conservation. 2010. Sampling Report: Surface Soil Lead Levels in Winnipeg, Manitoba: 2007 and 2008. Manitoba Conservation Report No. 2009-03, Winnipeg, MB.

In 2006, Pinchin Environmental conducted a site investigation at the Barber House property in North Point Douglas which identified concentrations of lead in soil that exceeded the CCME guideline. Samples collected from the northern portion of the property were comprised of fill material. Therefore, it is unknown if lead concentrations in these samples may have been influenced by materials brought on site. This prompted Manitoba Conservation to review historical data on lead concentrations in the inner city of Winnipeg which indicated that a large number of sampling sites contained concentrations of lead that exceeded the CCME guideline.

In 2007, the Habitat Management and Ecosystem Monitoring Section of Manitoba Conservation sampled sites from schoolyards, playgrounds, and boulevards in residential areas that were previously sampled during the 1980s to determine if lead concentrations in soil had changed over time. The report notes that the previous studies of Winnipeg soils identified lead soil exceedances as concentrations above 2,600 µg/g, the criterion in effect at the time of the previous investigations. Soil removal and replacement had occurred at several locations since the previous soil survey. This report also refers to an unpublished study conducted by Manitoba Environment in 1988 in which elevated concentrations of lead were identified in the Point Douglas area near major roadways as well as two metal scrap yards on Sutherland Avenue. There is also reference to a 1997 study in which concentrations above the guideline were identified in soil samples collected from community garden plots in the inner city.

Following the completion of the 2007 sampling and the analysis of the results, an additional survey was conducted in 2008 which focused on the collection of soil, sand, pea gravel, and other surface materials from City playgrounds and sports fields in the vicinity of potential current and historical point sources of lead. The CCME human health guideline of 140 µg/g was the applicable criterion used in the study.

<u>Methodology</u>

The 2007 study collected samples from six (6) playgrounds (*i.e.*, Archibald Tot Lot, Hespeler Park, Home Playground, Jacob Penner Park (formerly Notre Dame Park), Maryland Tot Lot, and Spence Tot Lot), seven (7) school yards, and boulevards in four (4) residential areas. The report indicates that a representative sub-sample of the sites from the 1980s surveys were selected for re-sampling in 2007.

For grassed areas from playground sites, separate samples were collected for the sod and the top 5 cm of the underlying soil. Two (2) to three (3) cores of sod and two (2) cores of soil, sand or aggregate material were sampled as composites. A composite sample of the top 2.5 cm of surface soil was also collected for five (5) of the playgrounds, where each composite sample consisted of a total of twenty (20) soil cores along an “X” pattern. For the school yard sites, a small whisk brush was used to collect loose soil, dust, and other particulate matter from paved, concrete, or graveled areas. In addition, twenty (20) cores of the top 2.5 cm of surface material were collected. Separate samples of sod and the top 5 cm of underlying soil at the Weston

Elementary School sports field were collected from twenty-one (21) sample sites. The sampling method from the1981 sampling survey was used in the 2007 sampling survey.

In the Wolseley/Minto, Riverview/Lord Roberts, and Glenelm/Chalmers residential areas, separate sod and soil samples were collected. In North Point Douglas, the top 5 cm of surface material was collected. In addition, the top 2.5 cm of surface material were collected at selected sites in North Point Douglas to compare results from different sampling depths.

A second sampling survey was conducted in 2008 which focused on surface soil, sand, pea gravel, and other surface aggregate material from City of Winnipeg playgrounds and sports fields. The report indicates that the 2008 sampling locations were associated with identified point sources of lead including three (3) secondary lead smelters which previously operated in the west end of the city, several scrap recycling yards and metal manufacturing operations, and rail yards and other heavily impacted industrial lands in the inner city. Soil samples were collected from within a 1500 m radius of each smelter, and a 200 m radius of each metal scrap/recycling yard. A smelter (Canadian Bronze Co. Ltd) that was located on Bury Street north of Logan Avenue closed in the 1990s and the property was remediated in 1999-2000. Two (2) other secondary lead smelters that operated in Winnipeg include the Canada Metal Co. smelter, which was located at St. James Street and Wellington Avenue in the St. James Industrial Park area, and the Northwest Smelting Co. smelter, which was located at the west end of Logan Avenue. The Canada Metal Co. smelter ceased operations in 2002 and the area was remediated in 2004. The Northwest Smelting Co. smelter also ceased operations in early 2000s.

The 2008 sampling locations included eighteen (18) playgrounds, thirteen (13) baseball diamonds, twelve (12) soccer pitches, and two (2) football fields. In addition, three (3) surface soil samples were collected from Westview Park. The sampling methods for the 2008 survey consisted of collecting separate surface soil, sand, and pea gravel samples. The top 2.5 cm of the soil profile were taken from grassed areas in playgrounds. Each sample consisted of a composite of twenty (20) cores which were collected in an “X” pattern. Sand and pea gravel were collected to a depth of 5 cm and three (3) cores were collected per sample. For the baseball diamonds, the infield and outfield areas were sampled separately. The infield areas were sampled to a depth of 2.5 cm and cores were extracted in a “+” pattern, and the outfields were sampled to a depth of 2.5 cm along two (2) parallel lines. Soccer pitches and football fields were sampled to a depth of 2.5 cm along two (2) transects forming an “X” pattern. Twenty (20) soil cores were collected per sample from each baseball diamond, and sports field.

<u>Results</u>

The report concludes that the 2007 and 2008 results, coupled with data collected in 1980s, show that contamination of lead associated with point sources of lead, such as smelters and metal scrap yards, are generally localized, while contamination along major roadways associated with vehicle emissions during the use of leaded gasoline extends to a broader number of areas.

Most of the sod, soil, and aggregate samples collected in 2007/2008 had lower lead concentrations than samples collected during the 1980s. The 2007 sampling survey identified a number of exceedances of the CCME guideline at the Weston Elementary School sports field, grass-covered areas in a number of playgrounds, and from residential boulevards, including the boulevard along Sutherland Avenue in North Point Douglas. Overall, lead concentrations in playgrounds and sports fields in the vicinity of point sources of emissions in the inner city were below the CCME guideline.

Table 2-6 summarizes the results from the 2007 sampling survey.

Table 2-6 Lead in Soil Survey Results Summary (2007) (Manitoba Conservation, 2010)

Area		No. of Sample Locations	No. of Sample Locations with Exceedances of the CCME Residential Guideline of 140 µg/g (% exceedances in parenthesis)	Lead in soil (µg/g)		
				Mean	Max	Min
Playgrounds (n=6)	Sod	25	7 (28%)	122	712	17.5
	Soil	29	13 (45%)	157	436	24.1
	Aggregate material	16	0	31	115	1.8
School yards (n=7)	Sod/Soil	37	5 (14%)	84	228	12
	Aggregate material	37	5 (14%)	81	307	3
Weston Elementary School Sports Field	Sod	20	16 (80%)	429	907	89
	Soil	21	19 (90%)	463	1,130	113
Residential (Riverview/Lord Roberts, Wolseley/Minto, Glenelm/Chalmers)	Sod	54	2 (4%)	51	200	9.2
	Soil	54	9 (17%)	83	369	9.1
North Point Douglas	Sod/Soil	23	17 (74%)	468	2,240	31.1

Playgrounds

A large degree of variability in soil lead concentrations was found between and within playground sites. Generally, concentrations at most playground sites were lower in 2007 than during the previous sampling event in 1984, although there were some exceptions to this trend. Large decreases observed at some sites were attributed to sod, soil, or aggregate enhancement or replacement. Despite the overall decrease in concentrations, five (5) of the six (6) playgrounds sampled in 2007 contained exceedances in sod and/or soil samples from the top 5 cm. No exceedances were identified in areas with aggregate materials, such as sand boxes and areas below swings and play structures, where toddlers and children are likely to frequent.

In the 2007 data, the maximum concentration of 712 µg/g was measured in the "Spence Tot Lot" for the surface sod layer, and a maximum concentration of 436 µg/g was measured in the top 5 cm for soil under sod in the "Maryland Tot Lot". The average concentrations in sod, surface soil, and aggregates were 122, 157, and 31 µg/g, respectively. These are lower than the average concentrations measured in 1984 (253, 210, and 88 µg/g for sod, surface soil, and aggregates, respectively).

School Yards

Manitoba Conservation noted that concentrations of lead decreased "quite dramatically" in school yards from the previous sampling event in 1983, with average concentrations decreasing from 1,125 µg/g in 1983 to 82 µg/g in 2007. These samples were collected from paved, concrete, or graveled surfaces. Since each of these school yards are bordered by a major traffic thoroughfare, the historical contamination was assumed to be related to vehicle emissions. The observed decreases in concentrations were attributed to the phasing out of leaded fuels by the late 1980s and the replacement of surface materials in several school yards. No exceedances were identified from paved/concrete/graveled surfaces for three (3) schools (Archwood Elementary, Weston Elementary, and Tyndal School), and only a single exceedance was identified for each of two (2) schools (Lord Nelson and Fort Rouge).

Elevated levels of lead in the sod and the underlying soil continue to be identified in the Weston Elementary School sports field. Concentrations of lead in sod decreased from 979 µg/g in 1981 to 329 µg/g in 2007. However, concentrations in the top 5 cm underlying the sod increased from an average of 192 µg/g in 1981 to 463 µg/g in 2007.

Residential Boulevards

Concentrations of lead in sod and soil samples collected from residential boulevards in Wolseley/Minto, Riverview/Lord Roberts, and Glenelm/Chalmers were notably lower in 2007 relative to 1983, with a small number of sites with concentrations above the CCME guideline. The previously identified relationship between soil concentrations and proximity to heavy traffic thoroughfares was less evident in the 2007 sampling results.

Although most sampling sites in North Point Douglas (from a depth of 5 cm) had lower concentrations in 2007 (average of 468 µg/g) then when originally sampled in 1988 (average of 1,025 µg/g), the majority of the sites (74%, or 17 of 23 samples) still had concentrations that exceeded the CCME guideline. Ten (10) sampling sites from North Point Douglas included samples collected from two depths (2.5 cm and 5 cm) as it was suspected that higher concentrations would be present in the upper surface layers due to the contribution from atmospheric deposition of particulates. However, for five (5) of the 10 (ten) sites, the concentration in the sample collected from the 2.5 cm depth was lower than the concentration in the corresponding sample collected from the 5 cm depth. The overall average concentration from the 2.5 cm samples (167 µg/g) was lower than the average for the 5 cm samples (202 µg/g).

2008 Sampling Program

The 2008 sampling focused on the collection of soil, sand, pea gravel, and other surface materials from City playgrounds and sports fields in the vicinity of potential current and historical point sources of lead. With the exception of the three (3) samples collected from Westview Park, concentrations of lead in sand and sieved dust samples from playground pea gravel were very low, with no exceedances of the CCME guideline reported. Only one (1) sample collected from surface soil samples collected from grassed areas in playgrounds exceeded the CCME guideline. This was the only exceedance found in the ninety (90) samples collected in the 2008 survey (with the exception of the three (3) samples collected from Westview Park). This sample (161 µg/g) was collected from Stanley Knowles Park located along Logan Avenue approximately 550 m east of the former Canadian Bronze smelter site.

The Westview Park samples were noted to be elevated in the 2008 sampling, with concentrations of 208, 356 and 368 µg/g. These concentrations were lower than those reported in 1988 (concentrations of 560, 850 and 1,265 µg/g) but were still in excess of the CCME guideline.

<u>Limitations and Uncertainties</u>

The report notes that the sites from the 1980s studies were not geo-referenced and as such, the locations in the 2007 sampling survey may not be the exact sample locations as the previous studies. The report also notes that the sampling protocol varied between the 1980s surveys. At some sites, it was reported to be difficult to distinguish between the sod and soil layers and this may have contributed to the variability in the results when comparing the data from the 1980s and the 2007 data.

2.2.13 *Pinchin Environmental. 2006. Phase II Environmental Site Assessment. 99 & 105 Euclid Avenue, Winnipeg, Manitoba. July 27, 2006 and December 29, 2006.*

In June 2006, Pinchin Environmental Ltd. (Pinchin) conducted a Phase II Environmental Site Assessment (ESA) of the property located at 99 and 105 Euclid Avenue, Winnipeg, located within the neighbourhood of North Point Douglas. The Site was vacant at the time of the investigation and included a derelict, historically significant residential building known as the Barber House. The objective of the investigation was to assess potential impacts to on-site soil and groundwater related to potentially contaminating activities on surrounding commercial and industrial properties, including a service station and a dry-cleaning facility. Concentrations of lead and other metals in soils exceeded the CCME guidelines in multiple samples. Based on these findings, Pinchin conducted a supplemental investigation in October and November 2006 to further delineate the extent of impacts of lead and other metals in soils. Concentrations of lead exceeded the CCME guideline in seventeen (17) of twenty-seven (27) surface soil samples collected from grassed areas across the site.

Methodology

During the initial investigation in June 2006, soil samples were collected from a depth of 0.75 metres below ground surface (mbgs) from three (3) boreholes advanced along Euclid Avenue. In addition, six (6) soil samples labelled as surface samples were collected from areas across the Site.

The supplemental investigation involved the collection of twenty-seven (27) samples in a 10 m by 10 m grid pattern. Samples were collected from below the sod root zone, generally at a depth of 0.3 mbgs, with some samples collected from within the root zone at an approximate depth of 0.1 to 0.15 mbgs. Additional samples were collected from test pits advanced within the northern portion of the Site in response to the observation of waste materials in landscaped mounds.

Results

Concentrations of lead exceeded the CCME residential guideline in five (5) of the six (6) surface samples collected in June 2006, with concentrations ranging from 70.2 to 439 µg/g. Concentrations of lead in each of the samples collected at a depth of 0.75 mbgs (4.97, 5.19, and 46.5 µg/g) were below the guideline.

During the supplemental sampling in October and November 2006, concentrations of lead exceeded the guideline in seventeen (17) of twenty-seven (27) surface soil samples, with concentrations ranging from 20 to 895 µg/g.

A summary of the concentrations of lead in surface samples collected in 2006 are provided in Table 2-7. The results for samples collected from boreholes and test pits were not included as they are not considered to be reflective of soils that the general population may be exposed to on a regular basis.

Table 2-7 Lead in Soil ESA Results Summary (Pinchin, 2006)					
Area	No. of Samples	No. of Samples with CCME Guideline Exceedances (>140 µg/g)	Lead in soil (µg/g)		
			Mean	Max	Min
Surface Samples (June 2006)	6	5	226	439	70.2
Surface Samples (October-November 2006)	27	17	310	895	20

Limitations and Uncertainties

The depth of surface samples from the initial investigation in June 2006 was not specified. During the supplemental investigation, samples collected from the northern portion of the property were comprised of fill material. Therefore, it is unknown if lead concentrations in these samples may have been influenced by materials brought on site.

2.2.14 University of Manitoba. 2017. Soil Sampling Results from the St. Boniface Area (unpublished).

The University of Manitoba conducted a soil study in fall 2017 in the St. Boniface area. A total of one hundred and seventy-four (174) soil samples were collected from commercial and residential properties within this neighbourhood, as well as two (2) sediment samples from a ditch. All soil samples were collected at a depth of 0 to 10 cm from locations that include residential properties (front and back yards, gardens), parks, vacant lots, and commercial properties. The sampling locations were generally only described by Street name and did not include addresses. Overall, less than 15% of samples contained concentrations that exceeded the CCME guideline, with less than 5% containing concentrations that were more than double the guideline (*i.e.*, 280 µg/g). The average concentration of all samples was well below the CCME guideline.

Exceedances were slightly more common in samples collected from front yards and gardens relative to back yards, although gardens may have been located in either the front or back yard. Sampling sites located on roadways that are anticipated to have heavier vehicular traffic did not have a higher frequency of exceedances, however, given that street addresses were not provided, it is unknown which (if any) sample sites were located on streets that intersected with major thoroughfares.

The results of this study are proprietary and cannot be presented in detail or summary.

2.2.15 Manitoba Sustainable Development. 2019. Winnipeg Soil Survey, Fall 2018. Environmental Compliance and Enforcement Branch. January 2019.

A soil survey was conducted by the Manitoba Sustainable Development Environmental Compliance and Enforcement Branch (ECE) in October 2018 to assess lead concentrations in soil in the City of Winnipeg. The survey focused on locations that were previously sampled during the study completed by the Province in 2007-2008. Previous soil studies concluded that lead contamination in soils near Weston Elementary School was likely a result of its close proximity to high traffic areas and historical leaded fuel use rather than emissions from the Canadian Bronze smelter located approximately 280 m north of the school.

The CCME guideline of 140 µg/g protective of human health for lead *via* soil ingestion was the applicable criterion used in the study. The 2018 survey identified exceedances of lead in soil at

Weston Elementary School, Westview Park, North Point Douglas (certain areas), and one sample from Glenelm/Chalmers. Each of these areas were identified as having exceedances in previous studies.

Methodology

In total, one hundred and twenty-seven (127) locations were sampled during this survey, including four (4) residential boulevards (*i.e.*, Wolseley/Minto as Group 1, Riverview/Lord Roberts as Group 2, Glenelm/Chalmers as Group 3, and North Point Douglas as Group 4); eighteen (18) schools, and thirty-two (32) parks and playgrounds. Areas in St. Boniface were also sampled. For the 2018 survey, there were a number of deviations from the sampling locations selected in the previous studies, including the following:

- Habitat Park was sampled in 2008 but was not in existence for the 2018 sampling survey;
- Samples were only collected along the edges of the schoolyard at Gordon Bell High School as the majority of the yard is now paved;
- Point Douglas Park and several schools were added to the 2018 sampling survey;
- Samples were collected at Norquay School; and,
- Samples were collected at a second sample site at Dufferin Elementary School.

The 2018 soil survey followed a similar sampling methodology as employed by the University of Manitoba in their 2017 St. Boniface soil study and as described in technical documents prepared by the CCME (2016a,b) and the US EPA (1995). Composite sampling was utilized to obtain a representative surface soil sample from each location. Discrete samples were obtained by collecting soil to a depth of 7.5 cm using a 2 cm diameter Oakfield soil sampler. Discrete subsamples were collected at intervals along an "X" pattern. Each composite sample consisted of ten (10) discrete soil subsamples. At Weston Elementary School, composite samples were obtained from each of the twenty-one (21) sample locations that were sampled in 2007; each composite sample consisted of five (5) discrete subsamples taken 30 cm from each other. One (1) additional composite sample was obtained in the southeast corner of the schoolyard that was not previously sampled in the 2007 study. For every tenth sample collected, a field duplicate was obtained for quality control and quality assurance measures. Sampling teams collected samples from the residential boulevards, parks and playgrounds from October 9 to 11, 2018, and schools were sampled on October 19, 2018.

Results

Table 2-8 summarizes the results from the 2018 sampling survey.

Table 2-8 Lead in Soil Survey Results Summary (2018) (Manitoba Sustainable Development, 2019)

Area		No. of Sites Sampled	No. of Sites with CCME Guideline Exceedances (>140 µg/g)	Lead in soil (µg/g)		
				Mean	Max	Min
Residential	Wolseley/Minto	18	0	37	105	11.3
	Riverview/Lord Roberts	20	0	50.7	125	14.2
	Glenelm/Chalmers	17	1	57.6	141	14.2

Table 2-8 Lead in Soil Survey Results Summary (2018) (Manitoba Sustainable Development, 2019)

	North Point Douglas	22	9	199.8	885	15.6
Parks and Playgrounds		32	2	72.1	439	15.9
Schools (excluding Weston School)		17	0	50.5	97.5	11.5
Weston School		22	18 (locations)	215.9	446.0	96.3

A total of seventy-seven (77) samples were collected in the residential areas, of which there were ten (10) exceedances of the CCME guideline reported. Although one of these exceedances was reported in one (1) of the seventeen (17) residential boulevards tested in the Glenelm/Chalmers area, this concentration (*i.e.*, 141 µg/g at Macintosh Avenue between Henderson and Brazier) was equal to the CCME guideline of 140 µg/g when rounded to two significant figures. The remaining nine (9) exceedances were identified in the North Point Douglas area along Stephens Street, Sutherland Avenue, and Syndicate Street. These exceedances ranged from 150 to 885 µg/g, with the highest results of 755 to 885 µg/g found on Sutherland Avenue at the southeast corner of Syndicate Street. It was reported that the overall lead concentrations in the sampled residential areas were lower than concentrations measured in the studies from previous years. Areas observed to have new curbs and grass had significantly lower concentrations.

Two (2) of thirty-two (32) parks sampled were reported to have exceedances. One (1) composite soil sample collected at Point Douglas Park (*i.e.*, 141 µg/g) was identified as an exceedance but was equal to the CCME guideline when rounded to two significant figures. One (1) composite soil sample collected at Westview park (*i.e.*, 439 µg/g) exceeded the CCME guideline. The 2018 study identifies that Point Douglas Park was not sampled previously but the 2018 results are consistent with the North Point Douglas residential area results. The Westview Park lead exceedance from 2018 is noted to be less than the concentration from the 1979 sample survey (*i.e.*, 1,265 µg/g). The 2018 study suggests that elevated lead concentrations at Westview Park may be a result of the previous use of this area as a landfill as concentrations in four (4) surrounding parks were below the guideline.

Of the eighteen (18) schools sampled, exceedances were only identified at Weston Elementary School. Eighteen (18) of the twenty-two (22) samples collected from the Weston School exceeded the guideline, with exceedances found across the school yard. The highest concentration (*i.e.*, 446 µg/g at WSA2) was found near the school tarmac and play structure in the northwest corner of the yard. The study noted a significant decrease in concentrations of lead at the Weston School since the 1981 survey, and that concentrations in 2018 were typically lower when compared to the 2007 survey results with the exception of a single sample location (A1). Seven (7) parks surrounding the school that were sampled had concentrations below the guideline.

<u>Limitations and Uncertainties</u>

Overall, it was acknowledged that the 2018 lead survey was not an exhaustive study of lead in soil in the City of Winnipeg. The intention of the survey was to identify any changes in concentrations over time in areas that were included in previous investigations. As the survey results are compared to results of the previous studies, the survey did not investigate possible sources of contamination or any additional areas that may have elevated concentrations of lead.

Although geo-referencing information was collected as part of the 2007/2008 sampling survey, this information was not available during the 2018 survey. As such, the sampling locations were approximated to replicate those from 2007/2008 and are anticipated to be in close proximity of the previous locations. Differences in the sampling locations are not likely to have a significant impact on the overall interpretation of trends in soil lead concentrations between the two surveys.

2.2.16 Environmental Site Assessment Reports on File with the Contaminated/Impacted Sites Program

A review was conducted of the complete list of all sites on file with the contaminated/impacted sites program. This list was first reduced to only include those sites located within the City of Winnipeg. It was further reduced to focus on those sites that were considered to have the potential to provide relevant soil lead data based on the site description listed within the database, as well as features observed by identifying the site on online satellite maps. Reports for nineteen (19) sites were selected for an initial review which indicated that these investigations were primarily conducted to characterize contamination related to petroleum hydrocarbons due to the presence of underground storage tanks or the use of the sites as retail fuel outlets or for bulk storage. Lead was included in the analysis of soil samples in a limited number of investigations, with the shallowest sample depth for each site being 0.75 mbgs. Soil concentrations at these depths are unlikely to be representative of conditions across a larger area or neighbourhood and are not generally reflective of soils that the general population would be exposed to on a frequent or prolonged basis. Given the nature of the investigations for many of the sites in the contaminated/impacted sites program, these data may not significantly contribute to the understanding of the distribution of lead in surface soils at a neighbourhood level. The exception was for a Phase II Environmental Site Assessment (ESA) completed by Pinchin for the Barber House property located within the neighbourhood of North Point Douglas (99-105 Euclid Street) as previously described.

3.0 TASK 2: IDENTIFICATION OF POTENTIAL CURRENT AND HISTORICAL SOURCES OF LEAD CONTAMINATON IN WINNIPEG

Canadians are exposed to lead from various natural and anthropogenic sources. Natural sources may include erosion of lead deposits and volcanic activity (Health Canada, 2013b). In Canada, the background concentration of lead in soils is estimated to be 9.65 µg/g, based on the mean concentration of 7,398 glacial till samples collected from across the country (Health Canada 2013a; 2013b; 2019a). Anthropogenic sources of lead may include primary (*e.g.*, smelting and refining) and secondary (*e.g.*, the use of lead-containing products and its incineration and/or disposal) sources (Health Canada, 2013b). Due to several desirable properties, including the ability to resist corrosion, lead has historically been used in a wide variety of products in both industrial applications and residential uses, particularly lead-storage batteries for vehicles, and general industrial products (*e.g.*, piping, cable covering, bearing metals for machinery, and sheet lead, etc.) (ATSDR, 2007; Health Canada, 2013a). Lead, in its various forms, has also been used in paints and as gasoline additives. The diverse anthropogenic uses of lead have made it ubiquitous in the environment (Health Canada, 2013a).

Particulate-bound lead emitted from mining operations, smelters, and combustion sources occurs primarily in the form of lead-sulfur compounds; however, in the atmosphere, lead exists primarily in the form of particulate-bound lead sulphate and lead carbonate and has a residence time of approximately 10 days (Corrin and Natusch, 1977; NAS, 1980; US EPA, 1986; Spear *et al*., 1998; MOE, 2006; ATSDR, 2007). Waste incinerators are known to be sources of lead, with the lead content varying in association with the waste stream. Coal combustion is also a major source of lead emissions on a global level, with emission levels peaking during months of high-power consumption. The burning of wood, most significantly during forest fires, can also release lead historically deposited in trees (US EPA, 2012). Once in the environment, lead may transform, but does not degrade and cannot be destroyed (ATSDR, 2007).

The amount of lead in soil in urban areas with light-industrial operations has been found to correlate with the size of the city (ATSDR, 2019). The resuspension of lead from brownfield sites and historical industrially impacted areas has been identified as a source of lead emissions in urban areas (US EPA, 2012).

According to Canada's Air Pollutant Emissions Inventory (APEI), annual lead emissions have decreased by 1.1 kilotonnes (kt), an 86% reduction, between 1990 and 2017. Currently, non-ferrous refining and the smelting industry is the major contributor to lead emissions in Canada (ECCC, 2019) (Figure 3-1).

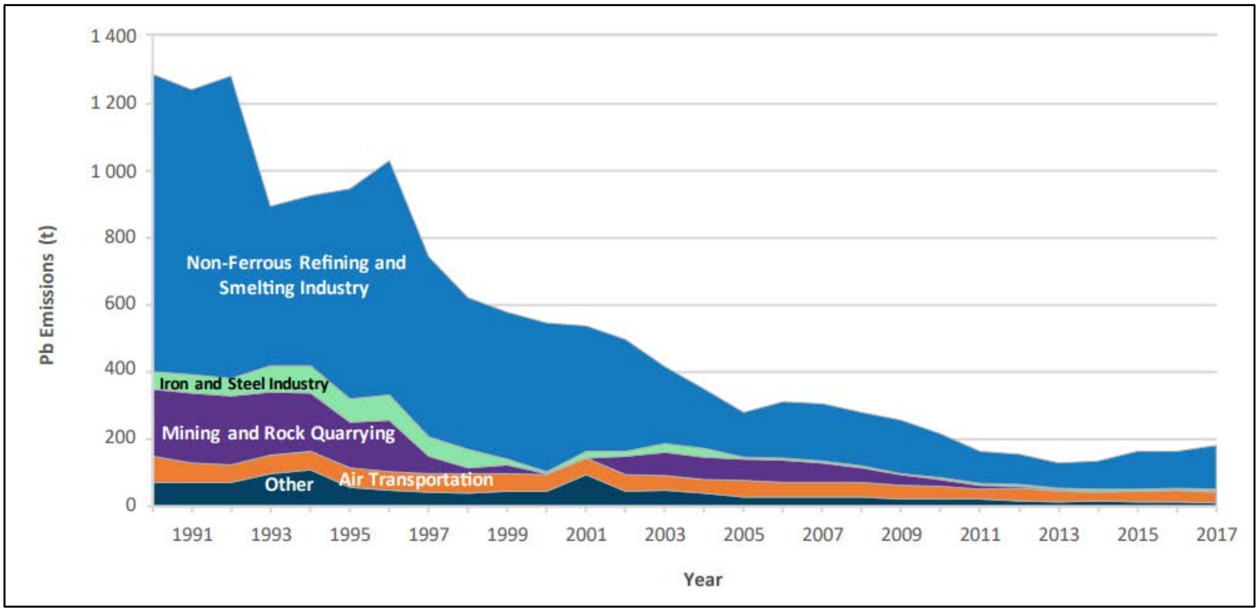


Figure 3-1 Lead Emissions in Canada by Industrial Sector, 1991 to 2017 (ECCC, 2019)

Soil is a major sink for lead deposited from the atmosphere. Generally, lead is immobile in soil due to the complexes it forms with organic matter; however, pH, mineral composition, microbial activity, ion exchange capacity, and the presence of inorganic colloids and iron oxides also influence transport and bioavailability (WHO, 1995; CCME, 1999b; US EPA, 2006; ATSDR, 2007). The mobility of lead in soil also varies with the different forms of lead released to the environment (CCME, 1999b). Soil properties also affect the speciation of lead within soil. In aerobic soils, lead compounds undergo weathering and may become more stable over time (CCME, 1999b). In anaerobic soils, much of the sulphate is reduced to sulphide which is a highly stable, insoluble, and a relatively non-reactive species of lead. Generally, lead does not bioaccumulate in terrestrial or aquatic food chains (ATSDR, 2007). Given the widespread uses of lead and its physical and chemical characteristics, it is typically found in upper soil layers, often through deposition of air emissions or direct releases to the soils.

Lead concentrations in Canadian soils are generally higher in cities and in close proximity to roads, industrial sources, weapon firing ranges, and buildings with deteriorating leaded paint (Health Canada 2013a; 2013b; 2019a; US EPA, 2012). Studies of lead in residential and parkland soils in several areas of Canada were evaluated between 2003 and 2010, with mean lead concentrations ranging from 35.6 to 766 µg/g, with most samples having concentrations below the CCME guideline of 140 µg/g (Health Canada, 2019a). Near point sources, lead concentrations in soil have been reported to have mean concentrations ranging from 13 to 750 µg/g.

A summary of the findings of Task 2 is provided in Section 3.1. Additional details on the identification of potential sources of lead in Winnipeg is provided in Section 3.2.

3.1 Summary of the Findings of Task 2

Several investigations were conducted in the City of Winnipeg in the 1970s and 1980s to characterize lead content in soil, sod, dust, and vegetation. Studies conducted by the Province indicated that several older neighbourhoods in the inner city had elevated concentrations of lead in soil that were primarily attributed to the presence of high traffic arteries (Manitoba Sustainable Development, 2019). Studies of on-road sources of lead found that approximately 75% of lead additives in fuels were emitted within the exhaust, while the remaining fraction was retained within the engine compartment. Due to the larger size of vehicle exhaust particles, the majority of emitted lead may have settled within 25 m of a roadway, however, elevated concentrations have been noted up to 100 m away.

In addition to emissions from the historical use of leaded gasoline, several point sources have also been identified as contributing sources within Winnipeg. Specifically, the three (3) secondary lead smelters previously operating in the west end of the City. Lead concentrations in soil in close proximity to these secondary lead smelters was frequently 10-fold those concentrations found to accumulate from normal vehicle emissions (Wotton, 1979).

Numerous additional point sources of lead have also been identified throughout the City. Soil samples collected by the Province in the 1980s and 2007 from boulevards and residential properties in the North Point Douglas neighbourhood were found to contain elevated lead concentrations within a zone of 60 m from scrap yards located along Sutherland Avenue (Manitoba Conservation, 2010). Similar facilities have been identified throughout the inner city. Although these facilities may not have emissions of lead from industrial processes, it is anticipated that airborne particulates created during physical manipulation of lead-containing products results in localized deposition to surrounding properties. Proximity to rail lines or industrial areas may also result in the accumulation of lead within surface soils. In general, areas closer to industrial sites with lead emissions have higher concentrations of lead in soil and vegetation.

Although lead-based paint is no longer utilized, older neighbourhoods in the City of Winnipeg may still be impacted by its historical use. Lead-based paint from older buildings may deteriorate and peel or chip from painted surfaces, accumulating in soils surrounding the buildings. Areas considered to be hot spots of high lead contamination in soils typically occur within 1 to 2 m of the painted surface (NZ MOH, 2012). Lead paint particles within interior and exterior dust can represent a significant source of lead exposure.

Based on information available in the investigations conducted by the Province, searches of various databases, and background information provided in the primary literature, various potential sources have been indicated to be contributing to concentrations of lead in soils throughout Winnipeg. The largest contributors are anticipated to be the former secondary lead smelters and vehicle emissions from major roadways due to the historical use of leaded gasoline. Given that the smelters have ceased operations, and leaded fuels have been phased-out from use in on-road vehicles, the historical primary sources of lead emissions for neighbourhoods in Winnipeg are no longer present.

Several neighbourhoods throughout the City were identified as being of potential concern due to elevated concentrations reported in the investigations described in Task 1. Based on the identification of numerous additional point sources of emissions, there are a number of areas that were not included within any of the soil investigations which may have received elevated historical rates of deposition. This includes the northeast area of the City where the Griffin

Canada Inc. facility was identified as having notable lead emissions, and in the neighbourhoods surrounding the airport (Figure 3-2). Given that major roadways are identified as a significant source of historical lead emissions, any neighbourhood that includes major traffic arteries may also represent areas of potential concern (Figure 3-3).

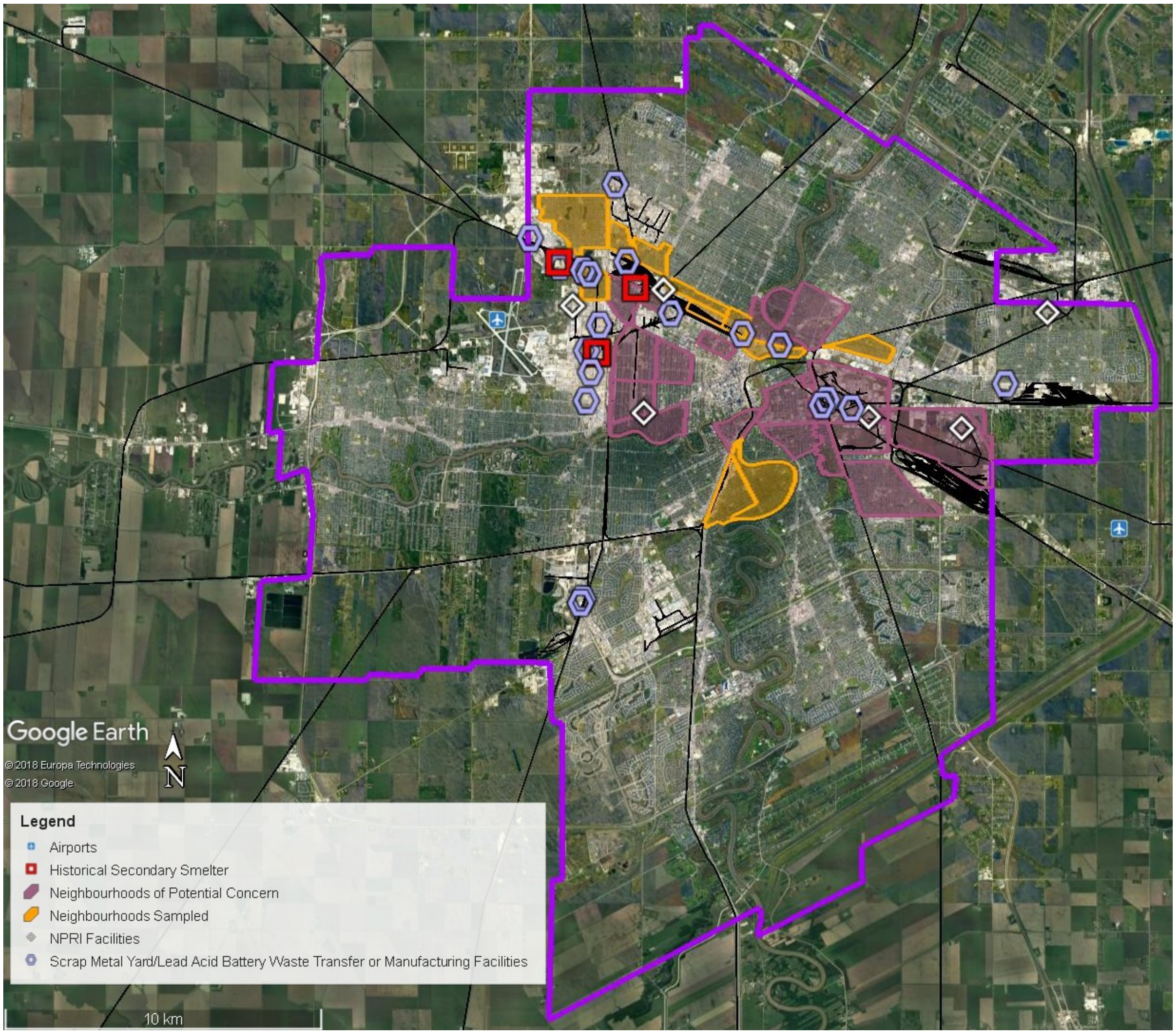


Figure 3-2 Point Sources of Lead Contamination in Winnipeg Presented with the Neighbourhoods Included in Soil Investigations

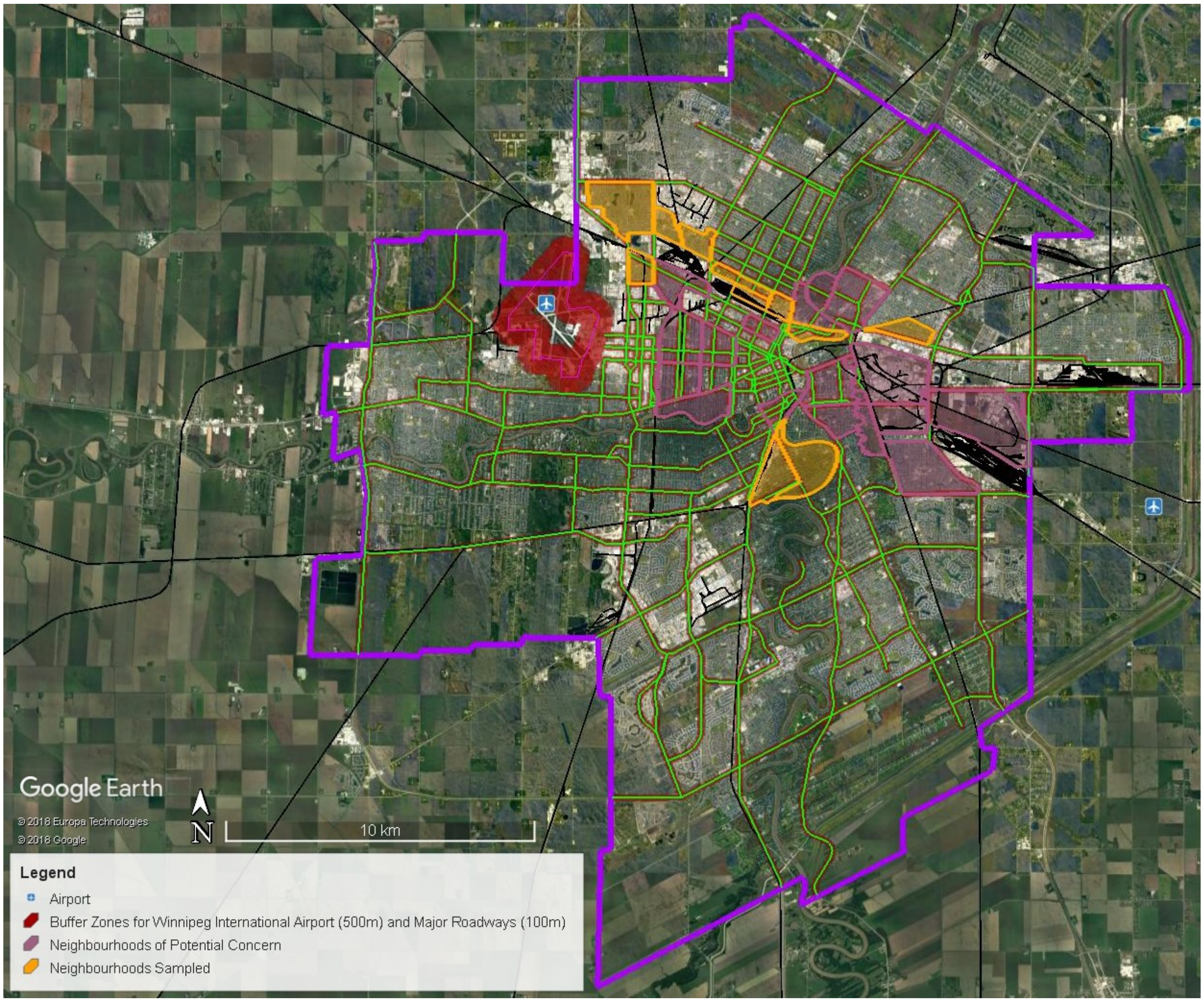


Figure 3-3 Sources of Leaded Gasoline Emissions Presented with the Neighbourhoods Included in Soil Investigations

3.2 Detailed Review of Potential Sources of Lead Contamination in Winnipeg

3.2.1 Secondary Lead Smelters and other Point Sources of Lead in Winnipeg

Following the phasing out of lead in fuels, the primary sources of lead in the environment are associated with mining, smelting, and industrial releases from facilities that use lead, lead alloys, and lead compounds (Health Canada, 2019a). Although several studies conducted by the Province and other researchers indicate that vehicle exhaust, due to the use of leaded gasoline, is the primary source of lead in soils in the City of Winnipeg, several point sources have also been identified as contributing sources. Specifically, the three (3) secondary lead smelters previously operating in the west end of the City. According to the 1984 status report on compliance with secondary lead smelter regulations (Environment Canada, 1985), a secondary lead smelter is defined as including one or more of the following operations:

(a) Smelting of lead scrap and lead-bearing material in a blast furnace or cupola. Emissions of lead-bearing particulates occur from materials handling, from charging of the furnace, in the flue gas from the furnace operation, and from metal or slag tapping.

(b) Melting and refining of lead scrap, lead pig and/or other lead bearing materials in a reverberatory furnace. Emission sources are similar to (a) above.

(c) Melting and refining of lead or lead alloy in a holding furnace or kettle furnace. Emission sources are similar to (a) above.

(d) Production of lead oxide from lead or lead compounds. Particulate emissions are greater than (c) above, and the lead concentration in the particulate is also greater.

(e) Receipt, handling or transfer of lead, lead alloys or lead bearing materials associated with the operations in (a), (b), (c) and (d) above.

Based on the 1984 report, the secondary lead producers specifically identified in Winnipeg were the Canada Metal Co. and Northwest Smelting and Refining smelters. The Canadian Bronze facility was identified as a facility whose primary operational purpose was to provide an intermediate material for further processing (Environment Canada, 1985). All three (3) smelters in Winnipeg ceased operations between the 1980s and early 2000s. Lead concentrations, in proximity to these secondary lead smelters, was frequently 10-fold the lead concentrations found to accumulate from normal vehicle emissions (Wotton, 1979).

In addition to the identified smelters, other activities such as metal scrap recycling yards, rail yards, and manufacturing operations were also identified as representing potential sources of lead (Figure 3-4) (Manitoba Conservation, 2010).

3.2.1.1 Smelters

Under the Secondary Lead Smelter National Emission Standards Regulation, which was issued under the Federal Clean Air Act in July 1976, regulations are provided which specify the maximum concentration for lead and particulate matter for various operations (Environment Canada, 1985) (Table 3-1).

Table 3-1 Emission Standards for the Secondary Lead Industry for 1984 (Environment Canada, 1985)

Parameter	Operations	Maximum Concentration
Particulate Matter	Blast Furnaces Cupolas Reverberatory Furnaces	0.046 g/m^3
Particulate Matter	Holding Furnaces Induction Furnaces Kettle Furnaces Lead Oxide Mills Scrap Handling Crushing Furnace Tapping Furnace Slagging Furnace Cleaning Casting	0.023 g/m^3
Lead	All operations	63% of particulate matter [a]

[a] Percentage may exceed 63% if concentration of particulate matter specified above is reduced to an equivalent of 63% lead contained within that particulate matter.

Each of the three (3) secondary smelters in the neighbourhood of Weston were identified to be subject to these regulations (Environment Canada, 1985). These three (3) facilities were exempted from the Clean Environment Act by a Provincial Order in Council as the Environmental Protection Service (EPS) in Manitoba implemented the regulations directly and routinely informs the provincial agency of its activities (Environment Canada, 1985). According to the 1984 status report on compliance with secondary lead smelter regulations, Canada Metal (at the Toronto, Winnipeg, and Calgary locations) and the Northwest Smelting and Refining smelter had an estimated full production capability of 34,000 tonnes and 10,000 tonnes of lead, respectively (Environment Canada, 1985). The results of the emission testing of particulate matter and lead at each of the three (3) facilities in Winnipeg are presented in Table 3-2.

Table 3-2 Performance Summaries of Facilities under Regulation in Winnipeg, Manitoba (Environment Canada, 1985)

Facility	Location	Emission Test Date	Results (mg/m^3)		Furnace Type and Other Sources	Particulate Control
			Particulate	Lead		
Canada Metal Co. Ltd.	Winnipeg	May 1984	0.49	0.09	1) Lead oxide Unit	Baghouse
			1.48	0.04	2) Reverberatory	
			0.62	0.04	3) Kettles	
Northwest Smelting and Refining Co. Ltd.	Winnipeg	May 1982	14.11	4.11	1) Blast	Baghouse
		August 1981	2.63	0.04	2) Kettles	
Canadian Bronze Co. Ltd.	Winnipeg	September 1982	0.37	0.05	Electric Induction	Baghouse

Currently, reporting to the National Pollutant Release Inventory (NPRI) inventory is a requirement by Environment and Climate Change Canada (ECCC) under the *Canadian Environmental Protection Act, 1999* (CEPA) (ECCC, 2016). According to the 2016 and 2017 guide for reporting to the NPRI, the reporting threshold for lead (and its compounds) was noted to be 50 kg manufactured, processed or otherwise used (MPO) lead, where "manufactured, processed or otherwise used" refers to the amount of the substance produced, prepared or used in any other way at a facility (ECCC, 2016). Further discussion on the NPRI inventory and search results is presented in Section 3.2.2.1 and Appendix A. Details for the three (3) smelters are presented below.

Canadian Bronze Company Ltd.

The Canadian Bronze smelter was located on 15 Bury Street, north of Logan Street, adjacent to a residential area approximately 280 m north of the Weston Elementary School (Jones and Wotton, 1983b; Manitoba Conservation, 2010; Manitoba Sustainable Development, 2019; Wotton, 1979). This smelter operated for several years before it was closed in the 1990s and remediated between 1999 and 2000 (Manitoba Conservation, 2010).

Soil data collected in the vicinity of the Canadian Bronze smelter in 1978 and 1979 identified concentrations as high as 450 µg/g and 780 µg/g at distances of approximately 700 m from the smelter to the southwest and west, respectively (Krawchuk, 1980; Manitoba Conservation, 2010). In 1981, the Province collected soil samples in transects extending from the smelter and noted that concentrations of lead fluctuated but that the results showed a general trend of decreasing concentrations with increasing distance from the smelter. Concentrations of lead as high as 1,000 µg/g were noted at the terminus of these transects (Manitoba Conservation, 2010). Overall, elevated concentrations of lead were identified within a radius zone of at least 450 to 500 m from the smelter (Manitoba Consumer and Corporate Affairs and Environment 1981 unpublished data). These elevated concentrations were noted to be likely influenced by multiple point sources, including vehicle exhaust due to leaded gasoline (Manitoba Conservation, 2010).

To further characterize lead impacts in the inner city, the study conducted by the Province in 2007/2008 initially identified the known and suspected point sources of lead, including the three (3) smelters, several metal scrap recycling yards and metal manufacturing operations, rail yards, and other heavily impacted industrial areas. Sample sites selected for the sampling program near playgrounds and other recreational areas were limited to a radius zone of 1,500 m from each of the smelters, and 200 m radii to the other identified point sources of lead. The results indicated that soil concentrations from point sources were very localized (Manitoba Conservation, 2010).

Canada Metal Co. and Northwest Smelting Co.

The Northwest Smelting facility was located at the west end of Logan Avenue at 2185 Logan Avenue. Operations at this smelter were discontinued in the early 2000s (Manitoba Conservation, 2010). The Canada Metal smelter was located at St. James Street and Wellington Avenue in the St. James Industrial Park area (ECCC, 2016; Manitoba Conservation, 2010; Wotton, 1979). It operated from 1954 to 1976, and between 1954 to 2002 the facility also included battery storage and smashing for the purpose of lead removal. Operations at the site ceased in 2002 and the area was remediated in 2004. The 1984 status report (Environment Canada, 1985) identified that compliance stack emission testing conducted at Canada Metal in June 1980 demonstrated that the facility's lead oxide production was not in compliance with the lead emission regulations. Environment Canada filed a case for the alleged violations against Canada Metals in February 1981. However, the case was tried in 1984 and the company was acquitted on all charges due to unreliable test results (Environment Canada, 1985).

In several studies completed in the area, lead soil concentrations in the immediate vicinity of the Canada Metal smelter were elevated (Krawchuk, 1980; Wotton,1979; Manitoba Environment, 1989 unpublished data), with concentrations (n=3) decreasing to 180 to 230 µg/g at a distance of 300 to 600 m from the facility (Krawchuk, 1980). An analysis of lead particulates in air and soil in 1982 indicated that the major source of lead deposition in the Weston neighbourhood was likely motor vehicle exhaust from Logan Avenue rather than emissions from the smelters (Wotton and Doern, 1983).

3.2.1.2 Metal Scrap Recycling Yards and Metal Manufacturing Operations

Soil samples collected by the Province in 1988 and 2007 from boulevards and residential properties in the North Point Douglas neighbourhood were found to contain elevated lead concentrations within a zone of 60 m from scrap yards located along Sutherland Avenue (Manitoba Conservation, 2010; Manitoba Environment 1989 unpublished data). These results are consistent with the results of a Provincial investigation in Brandon, Manitoba in 2005 which identified elevated concentrations of lead in soil within a zone of approximately 75 m of a battery recycling scrap yard. Although these facilities may not have emissions of lead from industrial processes, it is anticipated that airborne particulates created during physical manipulation of lead-containing products results in localized deposition to surrounding properties. Figure 3-4 presents the locations of a number of identified scrap metal yard/lead acid battery waste transfer or manufacturing facilities which may have the potential to affect soil quality in the surrounding areas.

3.2.1.3 Rail Yards and Other Heavily Impacted Industrial Areas

Proximity to rail lines or industrial areas could also result in the accumulation of lead within surface soils (Manitoba Sustainable Development, 2019). In general, areas closer to industrial sites with lead emissions have higher concentrations of lead in soil and vegetation. Proximity to railroads can also influence soil lead concentrations as historical coal burning and diesel exhaust from railroads may be contributing factors. A study in Alabama indicated that for each 100 m increase in the distance from the railroads, a 3.6% decrease in soil lead concentrations was evident (Ha *et al*., 2016).

The Canadian Pacific Railway (CPR) Weston Yards, CPR Winnipeg Yards, and the Fort Rouge Yard were identified as being potential point sources of lead (Manitoba Conservation, 2010). In addition, several schools that were historically sampled (Jones and Wotton, 1983b) (*e.g.,* Archwood School, Weston Elementary School, and Fort Rouge School) are in the vicinity of railway lines and yards. Although the available reports presented in Section 2.2 do not discuss potential impacts of railways on the surrounding areas, railyards and rail lines may be potential contributors to the elevated concentrations of lead identified in soils.

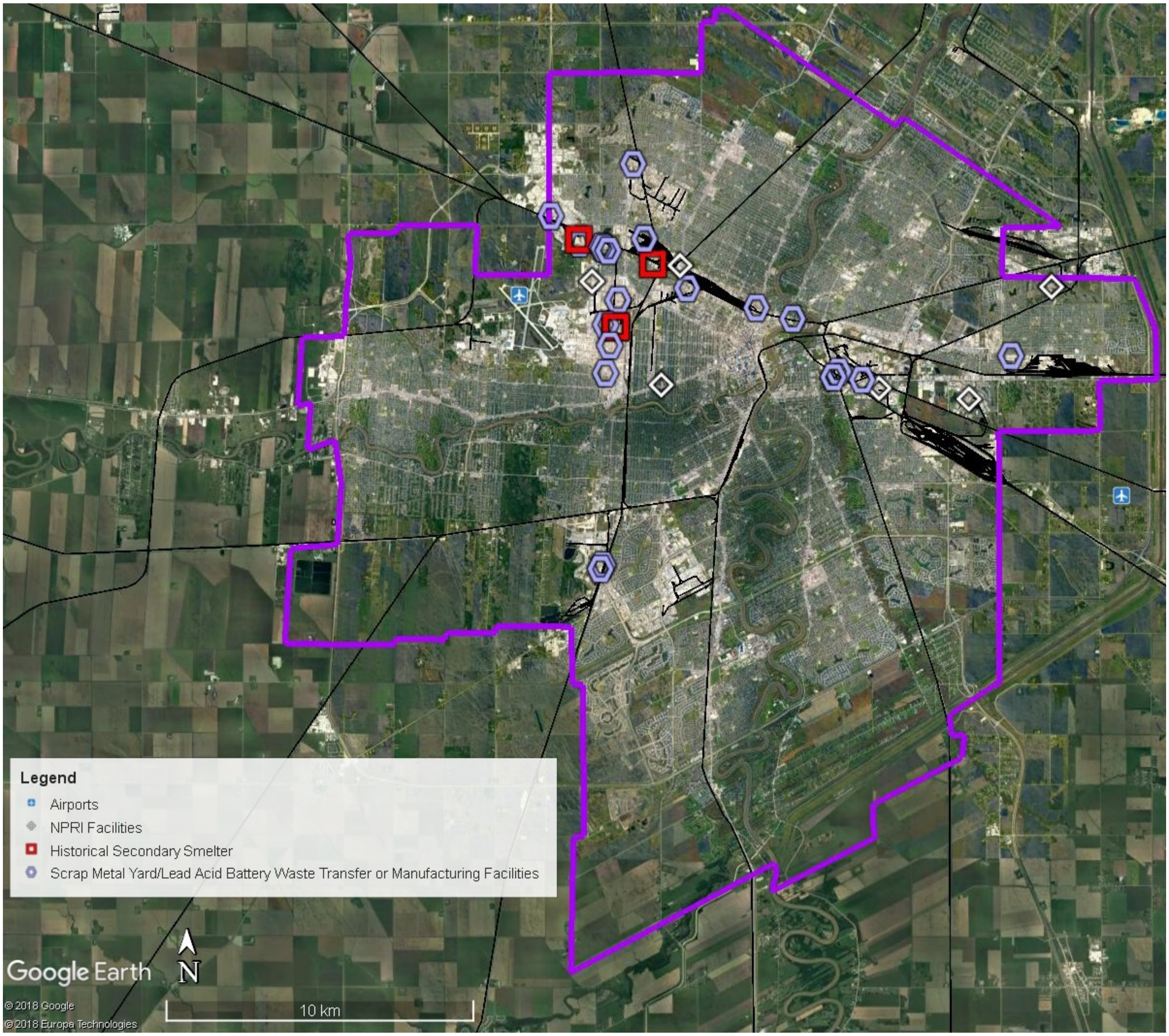


Figure 3-4 Point Sources of Lead Contamination in Winnipeg

3.2.2 Database Searches for Possible Emission Sources

Several searches were conducted to identify potential current and historical sources of lead in Winnipeg. These searches primarily focused on the following databases:

- The National Pollutant Release Inventory (NPRI); and,
- Manitoba Environmental Assessment and Licencing Public Registry Search.

Further details on search strategies, criteria, and results are presented in Appendix A.

3.2.2.1 NPRI Search

The NPRI is Canada's publicly accessible database of facilities and pollutants. The inventory allows for the identification and monitoring of sources of pollution from facilities across Canada and is mandated under the *Canadian Environmental Protection Act, 1999* (CEPA) (ECCC, 2016). The reporting requirements for 2016 and 2017 reporting years identified lead (and its compounds) to be a Part 1B substance with a reporting threshold of 50 kg (ECCC, 2016). The NPRI online query tool was utilized to identify any current and historical facilities that are releasing lead or have released lead in large quantities to the environment by filtering by substance, reporting year, and location (ECCC, 2018). Table 3-3 presents the search query inputted in the online tool.

Table 3-3 Search Query for NPRI Inventory

Search information	Inputted Search Criteria
Reporting Year	2017 to 1994
Substance (First Query); CAS Number	Lead (and its compounds); NA-08
Substance (Second Query); CAS Number	Tetraethyl lead; 78-00-2
Location	Community of Winnipeg (MB)
Facility	All Facilities
Industrial Sectors	All Sectors
Release/Disposal/Transfer Categories	All Types

Between 1994 and 2017, two facilities (*i.e.,* Griffin Canada Inc. and Canadian Pacific Railway - Weston Powerhouse) in the City of Winnipeg were identified to have air emissions greater than the 50 kg reporting threshold. The Griffin Canada Inc. facility is located in north-eastern Winnipeg at 2500 Day Street, and the Canadian Pacific Railway (Weston Powerhouse) is located in the Weston neighbourhood at 478 McPhillips Street. The highest on-site releases of lead to air between reporting years 1994 and 2017 at Griffin Canada Inc. and Canadian Pacific Railway - Weston Powerhouse were reported to be 80 kg and 52 kg, respectively. Three (3) additional facilities (PPG Phillips Industrial Coatings, Howden Alphair Ventilation System Inc., and SNC Lavalin Profac) were reported to have lead air emissions, however, releases were below the reporting threshold. Details of releases by reporting years and facilities are presented in Table 3-4 (with additional information provided in Appendix A).

Table 3-4 Applicable Facilities with On-Site Air and Land Releases

NPRIID	Facility	Address	City	Province
1344	Griffin Canada Inc. - GRIFFIN CANADA - WINNIPEG	2500 Day Street	Winnipeg	MB
2454	Cloverdale Paint Inc. - Guertin Coatings div. of Cloverdale Paint Inc.	50 Panet Road	Winnipeg	MB
26120	Howden Alphair Ventilating Systems Inc. - Howden Aliphair - Winnipeg Facility	1221 Sherwin Road	Winnipeg	MB
762	PPG PHILLIPS INDUSTRIAL COATINGS INC - PPG PHILLIPS INDUSTRIAL COATINGS - WINNIPEG	95 Paquin Road	Winnipeg	MB
22943	SNC LAVALIN PROFAC - RCMP D DIVISION	1091 Portage Avenue	Winnipeg	MB
10826	CANADIAN PACIFIC RAILWAY - WESTON POWERHOUSE	478 McPhillips Street	Winnipeg	MB
5268	CANADA METAL (WESTERN) LIMITED	1221 St. James St.	Winnipeg	MB

Given that the NPRI database only provides data from 1994 to 2017, it will not capture many of the historical point sources of lead emissions (*e.g.*, the secondary smelters). Only one (1) of the three (3) known secondary smelters (*i.e.,* Canada Metal Smelter) was identified in the NPRI data search, and entries were only from reporting years 1998 to 2002. As a result, other potential methods for identifying historical sources of lead were required, including a review of the Manitoba Public Registry for lead air emissions.

Figure 3-5 presents locations of facilities with on-site releases to air and land. Secondary lead smelters were assumed to have a zone of influence of 500 m. Facilities identified within the NPRI database with air emissions are anticipated to have a zone of influence of 200 m. Scrap metal yard/lead acid battery waste transfer or manufacturing facilities are anticipated to have a zone of influence of 60 m. These facilities are identified in relation to neighbourhoods that were included in one or more of the soil investigations described in Task 1.

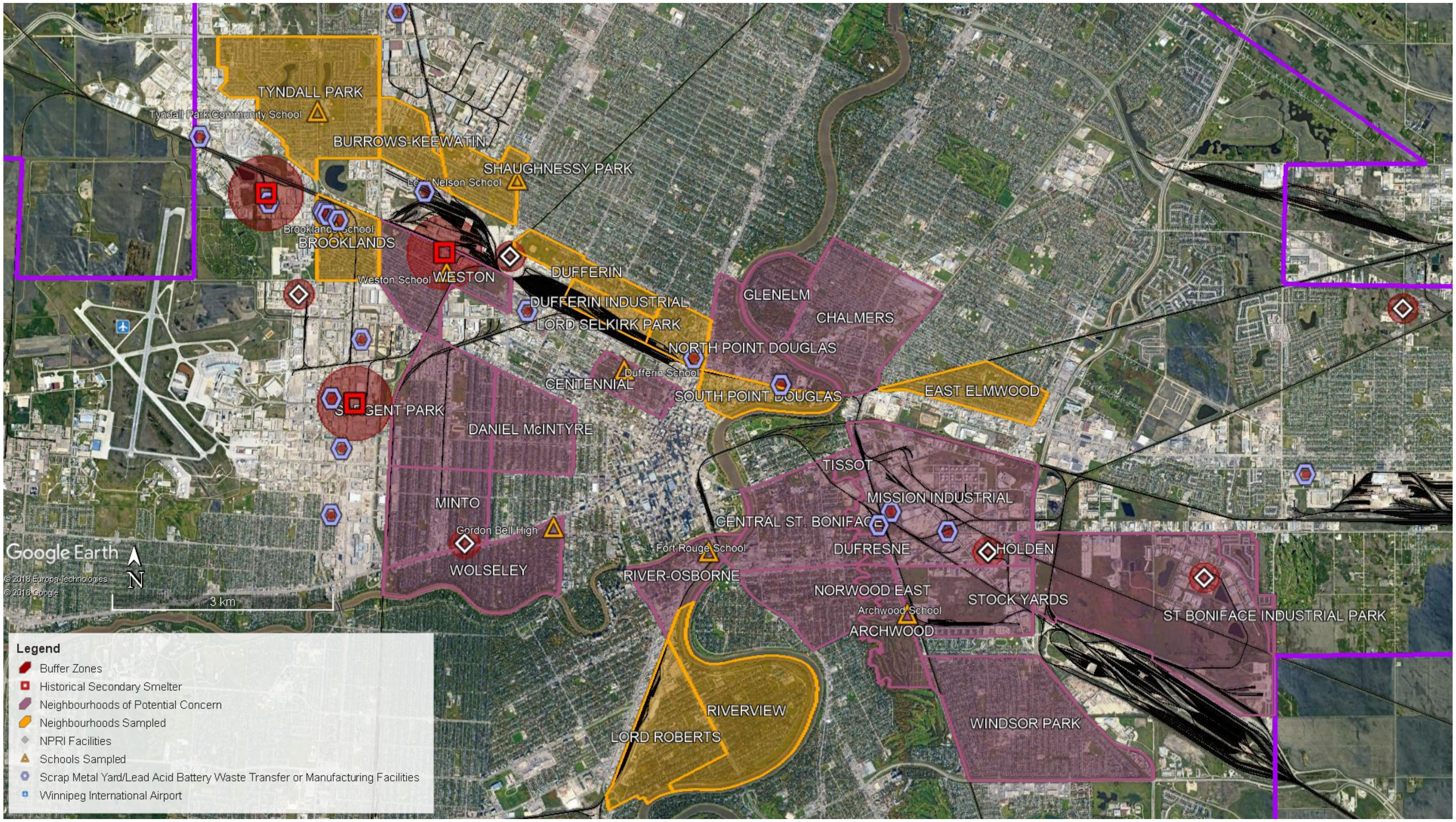


Figure 3-5 **Potential Zones of Influence for Smelters (500 m), Scrap Metal Yard/Lead Acid Battery Waste Transfer or Manufacturing Facilities (60 m), and Facilities Identified Within the NPRI (200 m).**

3.2.2.2 Environment Assessment and Licencing Public Registry

A search of the Environmental Assessment and Licencing Registry resulted in the identification of three (3) non-ferrous foundry facilities in the City of Winnipeg, including the Canadian Bronze smelter, Nuwest Alloys, and Dixon Group Canada. Canada Metal smelter was not identified through this registry search. Several other potentially applicable facilities were identified, including:

- Waste lead acid battery transfer facilities,
- A lead-acid battery manufacturing plant;
- Scrap processing and auto wrecking facility
- Shell Oil refinery, and,
- Other manufacturing activities.

It is anticipated that this Registry would capture the major contributors to lead emissions as it is a reporting requirement under the *Environment Act* (which dates to 1988) and the *Clean Environment Act* (which was enacted in the 1970s). The Registry indicates that several facilities have requirements for emission monitoring, however, emission reports for facilities listed in the Registry could not be located or obtained. Facilities identified through the Registry search are further described in Appendix A and have been presented on Figure 3-4.

3.2.3 Urban Sources of Lead Emissions

Historical use of lead in gasoline is a potential source of lead exposure in modern urban environments due to the lack of mobility and degradation of lead in soils (ATSDR 2019; Health Canada 2019a). The use of lead in various fuels and automotive parts has contributed to the deposition of lead into soils, particularly in proximity to roadways and urban environments.

3.2.3.1 On-Road Sources of Lead

The use of tetraethyl and tetramethyl lead in fuels started to decline worldwide in the 1970s, with the complete phase-out in fuel for on-road vehicles in Canada taking place after 1989 (TCLTF, 2001). Between 1970 and 2011, a 99.6% decline in national lead emissions within the US was observed (ATSDR, 2019). This reduction (along with the reduction of lead in other sources) has contributed to substantial declines in BLLs observed in children from the 1970s to the 1990s in the US and Canada.

Unleaded fuels (*i.e.,* gasoline, diesel) and lubricating oils may still contain lead as an impurity originating within crude oil, resulting in the continued identification of lead in automobile tailpipe emissions (US EPA, 2012). Vehicle parts, including wheel weights and metallic brake pads and tires, can also contain lead which can be released as particulates to the surrounding environment. Although the use of lead-containing wheel weights has been banned in several US States, they are still currently in use. It has been estimated that in the US, 480 tonnes of lead are deposited onto roadways each year (US EPA, 2012).

Studies by the US EPA of on-road sources of lead found that approximately 75% of lead additives in fuels were emitted within the exhaust, while the remaining fraction was retained within the engine compartment. Due to the larger size of vehicle exhaust particles (*e.g.* greater than 10 µm), emitted lead particles likely settled locally (US EPA, 2012). The ATSDR (2019) notes that particles with diameters of more than 2 µm are deposited rapidly and within 25 m of a roadway. However, lead bound to smaller particles could be transported longer distances. Lead concentrations in soils adjacent to roadways have been reported to contain 30 to 3,000 µg/g more lead than soils considered to be reflective of background conditions (ATSDR, 2019).

At a distance of 500 m from an interstate highway with heavy traffic in Los Angeles, California, lead concentrations in air have been found to be comparable to local urban background conditions (US EPA, 2012). A study of surface soils along roadways in Baltimore, Maryland, observed that concentrations within 100 m of a roadway were significantly higher than soils beyond 100 m, with the highest median concentrations identified in samples from freeways in residential areas (112 µg/g), followed by samples from residential arterial roadways (98 µg/g) and industrial freeways (90 µg/g) (ATSDR, 2019). A recent study of a major roadway in Europe observed that lead concentrations were highest in soils approximately 5 m from the roadway and were lower immediately adjacent (within 1 m) and beyond 10 to 15 m of the roadway (Jankowski *et al*., 2018). The soil lead attributable to historical vehicle emissions is noted to vary within urban areas in relation to the potential for surface runoff with precipitation, vegetation cover, wind, and degree of soil turnover (US EPA, 2012).

Several studies completed by various researchers and the Province in the City of Winnipeg indicate that the primary source of lead in soils is vehicle exhaust due to leaded fuels. Jones and Wotton (1983) concluded that the highest concentrations of lead in soil were generally found on residential streets which intersected with major roadways, with concentrations observed to decrease with increasing distance from the thoroughfare. This relationship was less evident during the 2007 Provincial investigation following the phase-out of leaded fuels in soil samples collected from several residential boulevards (*i.e.,* boulevards in Wolseley/Minto, Riverview/Lord Roberts and Glenelm/Chalmers). At the Weston Elementary School sports field, a slight decrease in concentrations of lead in the sod layer and the top 5 cm of soil under the sod layer was noted in 1981 as the distance from Logan Avenue increased; however, this trend was not observed in the 2007 data (Manitoba Conservation, 2010).

To identify areas within Winnipeg that may have been significantly impacted by historical vehicle emissions, roads with four (4) lanes or greater were identified as major roadways. In addition, a traffic report from 2018 by the City of Winnipeg was utilized to determine which roadways are most frequently used (City of Winnipeg, 2019a). Figure 3-6 presents the major roadways in the City with a buffer of 100 m indicating the potential area of deposition from vehicle emissions.

3.2.3.2 Non-Road Sources of Lead

In Canada, lead in gasoline is restricted to use for piston aircrafts and competition racing vehicles as per the Gasoline Regulations under the *Canadian Environmental Protection Act*, 1999 (Canada, 1999; Health Canada, 2013b). As such, airports and racetracks may continue to be contributing to lead exposure (Health Canada, 2019a).

Aviation fuels for piston-engine aircraft have been identified as a key source of lead emissions in the US as well, and several forms of lead have been identified in these fuels, including tetraethyl lead, lead bromide, and lead oxybromide (the latter formed as by-products). Emissions from the use of these fuels have been reported to contain both particulate and aerosolized lead. Lead emissions from piston-engine aircraft can vary with fuel consumption rate, the type of engine and airframe combination used, and the mode of operation (US EPA, 2012). Elevated BLLs have been reported in children living within 500 m and 1000 m of an airport in North Carolina where leaded aviation fuel was used (Health Canada, 2019a; Miranda *et al*., 2011). The largest impact was on children living within 500 m of an airport which used aviation gasoline (Miranda *et al*., 2011). Figure 3-6 presents the airport and a buffer zone of 500 m.

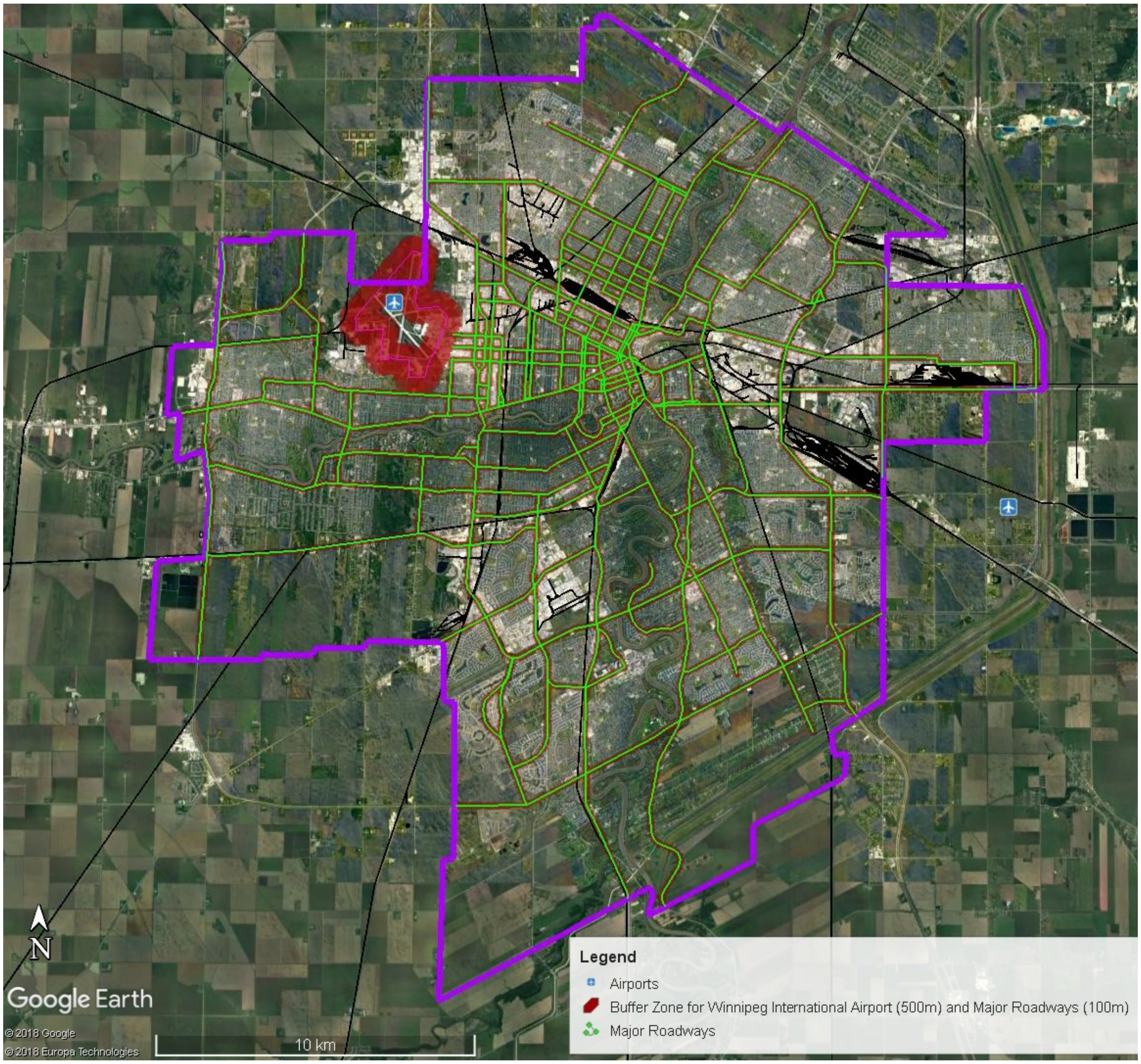


Figure 3-6 Sources of Emissions from Leaded Gasoline.

3.2.4 Lead Paint

Until the 1960s, lead, in the form of lead (II) chromate, was added to paints as a pigment and drying agent (Health Canada, 2013; 2019a). Although the use of lead in paints has declined or been eliminated, older homes and other buildings may still be sources of lead exposure to the surrounding environment (Health Canada, 2019a). Lead-based paint from older buildings may deteriorate and peel or chip from painted surfaces, accumulating in soils surrounding the buildings. Areas considered to be hot spots of high lead contamination in soils typically occur within 1 to 2 m of the painted surface (NZ MOH, 2012). Lead paint particles within interior and exterior dust can represent a significant source of lead exposure.

Several investigations conducted in the City of Winnipeg have indicated that soil lead concentrations at some sites may be significantly influenced by the weathering of lead-based paint (Pinchin Environmental, 2006; Manitoba Conservation, 2010). At the Weston Elementary School, lead-based paint was suspected to be contributing to elevated concentrations of lead in soil and surface dust (Jones, 1985; Manitoba Sustainable Development, 2019). Remedial action included the removal of lead paint on outdoor walls of the school and the replacement of soil and sod (Jones, 1985). Samples collected from seven (7) additional schools in 1983 indicated that samples which were suspected to have been contaminated with paint chips generally had the highest concentrations of lead in soil (Jones and Wotton, 1983b).

Although lead-based paint is no longer used, older neighbourhoods and buildings in the City of Winnipeg may still be impacted by its historical use and as such may represent areas of concern.

3.2.5 Lead in Drinking Water

Concentrations of lead in municipally supplied drinking water are typically low. Exposure to lead in drinking water may be sourced by lead plumbing/service lines, solders and fittings (Health Canada, 2019a). Until 1975, lead service lines were utilized in drinking water systems across Canada; lead solder was used until 1986 (Health Canada, 2019a). Although the use of lead in plumbing systems has been prohibited in Canada in the past decades, many drinking water systems may still be a source of lead, especially in older neighbourhoods where houses were constructed prior to the 1990s. Factors which contribute to lead leaching into drinking water include the age of the lead plumbing lines, the amount of time that the water remains stagnant in the service lines, and general water chemistry (*e.g.*, temperature, pH, alkalinity, chloride levels) (Health Canada, 2019a). Corrosive waters with higher chloride levels and a higher chloride-to-sulfate mass ratio may lead to higher lead concentrations in drinking water. As lead is usually introduced to drinking water after it leaves the treatment facility, corrosion control is one of the primary treatment measures for lead (Health Canada, 2019a).

Based on lead sampling conducted at sixty-five (65) sites in all provinces and territories for the National Survey of Disinfection By-Products and Selected Drinking Water Contaminants in Canadian Drinking Water, the average lead concentrations in Canadian drinking water have been determined to be 0.9 µg/L in winter, with a range <0.5 to 8.2 µg/L, and 1.27 µg/L in summer, with a range <0.5 to 24 µg/L (Health Canada, 2019a).

In Winnipeg, it is anticipated that most homes are not impacted by lead in drinking water due to non-detectable lead concentrations in the City's source water, and the implementation of lead control programs (City of Winnipeg, 2019b). As of June 2000, the City of Winnipeg has an ongoing program which involves the addition of orthophosphate to drinking water as a corrosion inhibitor to control the release of lead from pipes (City of Winnipeg, 2019b). Monthly testing has confirmed that concentrations of lead have consistently met the previous Federal Drinking Water Guideline of 10 µg/L. As of March 2019, Health Canada has reduced this drinking water guideline to 5 µg/L (Health Canada, 2019a). In response to this decrease, the City will be conducting a program in which drinking water samples are collected from a few hundred homes between June and Fall 2019 since many homes continue to have lead pipes and fixtures.

The City of Winnipeg distribution system water quality test results are available online (City of Winnipeg, 2019c). The City monitors water quality at Shoal Lake before it enters the treatment facility, and after the water has passed through the treatment processes (City of Winnipeg, 2019d). The average concentration of lead in treated water from January 1 to December 31, 2018 was reported to be 0.17 µg/L, with a range of <0.05 to 1.8 µg/L (City of Winnipeg, 2019d). Since lead is typically introduced in drinking water through leaching from the distribution system components, the basis of the compliance for many provinces and territories is often based on a flushed sample. However, it is important to note that this sampling protocol may not be a true representation of the exposure to lead in drinking water and may provide an indication of the minimum concentrations of lead (European Commission, 1999; Health Canada, 2019a).
It is estimated that approximately 87% of homes in the City of Winnipeg do not have lead pipes (Figure 3-7) (City of Winnipeg, 2019b).

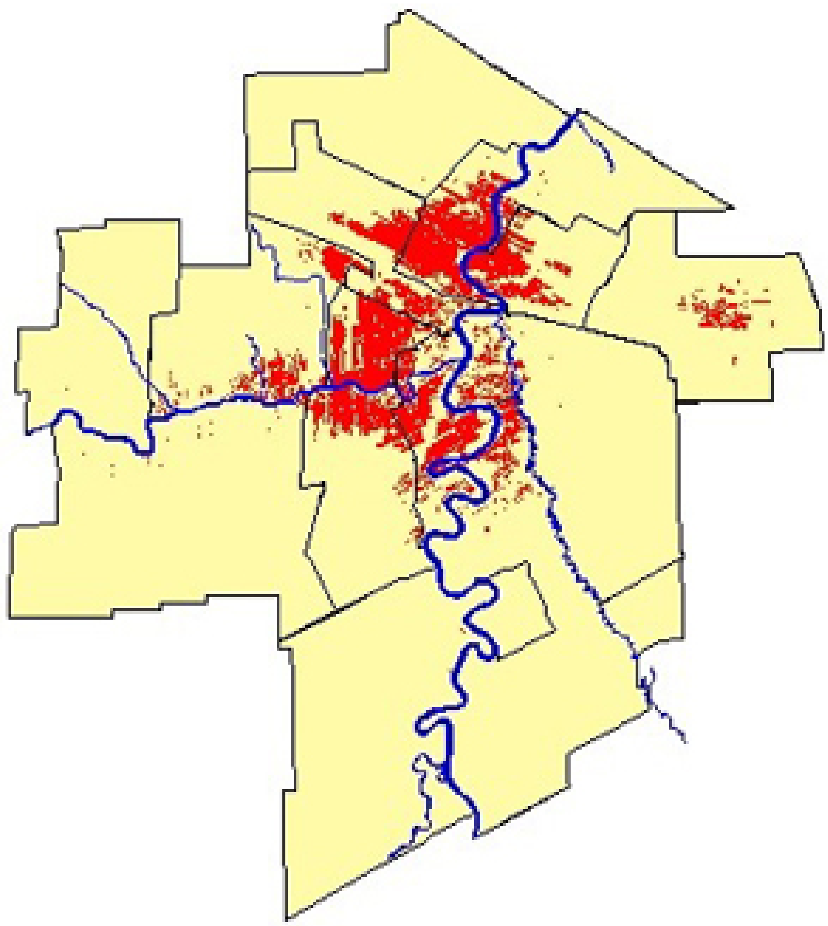


Figure 3-7 Areas Within the City of Winnipeg Which may have Lead Water Pipes (City of Winnipeg, 2019d)

3.2.6 Other Sources of Lead Exposure

In addition to the sources presented above, there are various additional sources which may also contribute to lead exposure. These include consumer products, food, and indoor house dust. Consumer products such as art supplies (*e.g.,* paints, crayons, modeling clays), inexpensive jewelry, and products utilized for recreational activities (*e.g.,* casting fishing weights, stained glass components, miniature soldiers and other collectors' figurines) may be a source of lead exposure (Health Canada, 2013b).

Lead is not permitted to be used in food products in Canada, but it has been detected in various foods as a result of processing, preparation, or exposure to lead during transport, and past use of lead arsenate as a pesticide in some areas. Lead shot from hunting is also a source of exposure in populations that consume wild game (Health Canada, 2019a).

For children, indoor air and dust may be a major source of lead exposure (Health Canada, 2019a). Household dust is a major source of exposure to lead in children due to frequent hand-to-mouth contact and crawling. Household dust levels are impacted by exterior soils, lead paint deterioration, tobacco smoke, and activities such as welding, pottery, and stained-glass crafting (Health Canada, 2019a).

For the purposes of this report, it is not anticipated that the sources presented in this subsection will significantly be contributing to historical and/or present sources of lead contamination in Winnipeg soils.

4.0 TASK 3: REVIEW OF APPROACHES TO ADDRESS LEAD IN SOIL

Task 3 included a review of the approaches used by Canadian and Western International jurisdictions for addressing concerns related to lead in soil. This review focused on those agencies that have utilized the current understanding of the toxicological effects of lead as a non-threshold contaminant. This review also considered risk management strategies implemented at the federal, provincial, and municipal levels, as well as those recommended by international agencies such as the US EPA and the WHO. A focused search of the peer-reviewed published literature was also conducted, identifying studies published after Health Canada's preparation of their "*Final Human Health State of the Science Report on Lead*" (Health Canada, 2013a), that relate to the assessment of lead in soil and the potential human exposures and health risks. A summary of the findings of Task 3 is provided in Section 4.1. A more detailed discussion is provided in Section 4.2.

4.1 Summary of the Findings of Task 3

The general objectives of this review were to:

- Identify the current levels of exposure to lead in Canada;
- Consider the current weight of evidence with respect to the potential effects of lead exposure in humans, with a focus on identifying a level of exposure or risk that various jurisdictions are currently using as the basis for intervention and risk management;
- Describe the available human health-based toxicity reference values from jurisdictions for lead and their basis;
- Identify and compare available soil quality guidelines for lead for the protection of human health, including approaches used in their derivation and best practices related to sampling for lead in soil, and how these relate to the current state of science; and,
- Compare risk management approaches employed by various jurisdictions with respect to lead exposure.

The key findings of this review were as follows:

- There is consistent evidence of adverse effects in children with BLLs less than 5 µg/dL, and there is no clear BLL or exposure threshold that is completely protective;
- The weight of evidence suggests that the dose-response curve for lead has characteristics of a non-threshold response. Most jurisdictions have withdrawn or are reviewing their non-carcinogenic toxicity reference values for lead as a result;
- A number of organizations have taken an incremental approach to evaluating health risks associated with lead, and response-levels associated with a 1 µg/dL increase in BLL in relation to potential changes in IQ levels in children have been developed. The most recent organization to take this approach is Health Canada (2019a) in the derivation of their revised drinking water guideline for lead;

- Health Canada has recently derived a non-threshold, blood lead model-based point of departure (POD) of 0.4 µg/kg-bw for lead, which is the basis of the revised Canadian drinking water guideline for lead;
- The Canadian residential soil quality guideline of 140 µg/g (or ppm) is based on pre-2000 science and on the surface does not reflect changes in the scientific evidence with respect to lead and health effects. Several soil quality guidelines from other jurisdictions, including the US EPA, also are affected by this issue. While the current Canadian residential guideline is more protective than comparable values from other jurisdictions, such as the US EPA soil screening level, Australia and several European countries, it is less conservative than guidelines from British Columbia and Ontario (both have residential guidelines of 120 µg/g for lead), as well as guidelines from California (residential guideline of 80 µg/g), and Michigan (residential clean-up of 40 µg/g). The current CCME guideline is also above lead guidelines derived for the protection of garden produce consumers by both the US EPA (gardening soil screening level of 100 µg/g) and Toronto Public Health (TPH) (soil screening values of 34 and 340 µg/g for lead in garden soil, with varying exposure reduction strategies suggested);
- An analysis by Wilson and Richardson (2013) and SNC Lavalin (2012), which included the use of Canadian-based exposure data and consideration of the current state of the science on lead toxicology, indicates that the current CCME guidelines for lead are adequately conservative; and,
- Lead exposure is considered a reportable disease in the Province of Quebec and all physicians are required to report the results of blood lead testing. Currently, no other Province or Territory in Canada has these requirements. However, in British Columbia, mandatory reporting of blood lead analyses is being considered. Overall, elevated lead exposure in Canada is infrequently reported. In several parts of the US, childhood blood testing is mandatory, as is the reporting of all blood lead results. Those States that require testing as part of surveillance and prevention programs also have approaches for managing elevated BLLs.

Various case studies indicate that the reduction or elimination of emissions are the most effective methods for reducing BLL in children residing in areas impacted by point-sources. This is consistent with the results of the systematic reviews and literature regarding intervention efficacy which indicate that education on lead exposure and the benefits of good hygiene, and interventions to control dust within households, may influence BLLs when used as part of a larger strategy that includes environmental reduction. However, when used on their own, education and household cleaning may have a limited to not effect on BLLs in children.

4.2 Detailed Review of Approaches to Address Lead in Soil

4.2.1 Lead Exposure in Canada and Other Western Jurisdictions

Lead exposure can have significant health and economic consequences. The WHO (2010a) notes that the costs associated with childhood lead toxicity are both direct (*e.g.*, medical costs) and indirect (*e.g.*, burden to society resulting from irreversible neurological effects). The WHO (2010a) estimated that each µg/dL increase in BLL is associated with a decrease in 0.25 IQ points, and that each point decrement in IQ results in a lifetime loss of economic productivity of

2.4%. Another analysis by WHO (2010b) noted that lead exposure on an international level, in 2004, was responsible for 143,000 deaths and 0.6% of the overall global burden of disease (expressed in disability-adjusted life years) through its contribution to the development of cognitive developmental deficits and adverse cardiovascular outcomes (WHO, 2010b).

More recently, the US EPA (2019) has completed an economic analysis associated with the proposed reductions in lead exposure in relation to the reductions in the dust-level hazard standards. The estimated benefits of reducing lead exposure *via* lower house dust standards range from $58 million to $2.3 billion per year in US dollars (USD). Further, the overall level of environmental protection for all populations within the US would be enhanced, without any disproportionately high impact on any minority or low-income group.

Children, especially those less than 5 years of age, are the most vulnerable to the effects of lead. It has been estimated that young children absorb approximately 4 to 5 times more lead than non-pregnant adults from the gastrointestinal tract. In addition, the overall intake of lead per unit body weight is higher for children, the blood-brain barrier is not yet fully developed, and adverse effects have been reported in children at exposure concentrations lower than in adults (WHO, 2010b). Boys have been observed to be more affected by the effects of pre-and post-natal lead exposure on neurological outcomes than girls (Desrochers-Couture *et al*., 2018). Breast milk is a significant source of lead exposure for infants (Health Canada, 2019a).

There is limited information available regarding the current levels of lead exposure within the City of Winnipeg. Overall, BLLs in Canadians have decreased over time, with reductions of more than 70% having been achieved since 1978-1979 (a time where the average BLL was 4.79 µg/dL). Blood lead levels are measured regularly as part of the Canadian Health Measures Survey (CHMS) – a national survey that represents 96% of the Canadian population and provides information regarding a number of different health measures. In the most recent cycle for which data are available (2016-2017, n=4,517, ages 3-79 years) the geometric mean BLL was determined to be 0.93 µg/dL for all ages combined (Health Canada, 2019b). In general, BLLs decreased from ages 3 to 19, and then increased with age, with the highest BLLs reported in older individuals (60-79 years). BLLs were generally higher in males than in females. In the 2016-2017 CHMS, the geometric mean BLLs for the various age groups were: 0.56 µg/dL (ages 3-5), 0.54 µg/dL (ages 6-11), 0.48 µg/dL (ages 12-19), 0.78 µg/dL (ages 20-39), 1.0 µg/dL (ages 40-59), and 1.4 µg/dL (ages 60-79). Within neighbourhoods with distinct sources of lead (*e.g.*, smelter emissions, areas with high lead shot consumption), the geometric mean BLLs have been reported to range from 1 to 5.6 µg/dL in children and 1.7 to 3.9 µg/dL in adults, with maximum reported BLLs in impacted areas recorded at 40 and 50 µg/dL in children and adults, respectively (Health Canada, 2019a).

An assessment completed in 2014 by the British Columbia Centre for Disease Control (BC CDC) evaluated the results of all blood lead samples collected and analyzed in British Columbia during the 2009 and 2010 period (excluding samples from the Trail blood lead screening program, workplace investigations, and workers compensation tests). A total of 6,770 blood lead test results were included. Five hundred and twelve (512) children ages 0 to 5 years of age in British Columbia had blood samples analyzed for lead. The 95th percentile for this age group during the 2009-2010 period was determined to be 3.9 µg/dL. A total of twenty-one (21) children (approximately 4%) were identified as having BLLs greater than 5 µg/dL, with eight (8) (1.6%) of those children having levels between 5 and 10 µg/dL, eleven (11) (2.1%) having BLLs between 10 and 15 µg/dL, and only two (2) children with BLLs measured between 15 and 34 µg/dL. The children with BLLs over 5 µg/dL were most frequently identified as residing in the Interior Health region of British Columbia (24% of children ages 0-5 years). All young children residing within the Northern Health region presented BLLs less than 5 µg/dL (BC CDC, 2014). Older children in British Columbia (ages 6-18 years) were identified as having the lowest BLLs out of all of those evaluated in the study (BC CDC, 2014).

A review by British Columbia CDC (2017) concluded that the effect of incremental increases in BLLs are likely to be the most pronounced at the lower BLLs (less than 5 µg/dL), and further reduction is likely to maximize positive neurodevelopment. School and daycare lead exposures *via* drinking water were noted to be potential exposure pathways for children in British Columbia, suggesting that certain buildings or areas may benefit from targeted intervention (BC CDC, 2017).

Similar trends in lead exposure have been reported in other Western countries, including the US and Australia. The US National Health and Nutritional Examination Survey (NHANES) is an on-going program of studies completed by the CDC that evaluate the health and nutritional status of children and adults within the US through data collected from interviews and physical examinations (CDC, 2019). Data from NHANES collected between 2015 and 2016 (n=4,988) revealed geometric mean BLLs of 0.758 µg/dL for ages 1-5 years, 0.571 µg/dL for ages 6-11 years, 0.467 µg/dL for ages 12-19 years, and 0.920 µg/dL for ages >20 years. The current CDC reference level for BLL is 5 µg/dL corresponds to the 97.5 percentile of BLLs in children, as observed by NHANES between 2007 and 2010 (CDC, 2019).

The 'background' BLL in Australia is estimated to be less than 5 µg/dL based on limited available data in children (NHMRC, 2015). Studies in pre-school children in the cities of Sydney and Fremantle have identified geometric mean BLLs of 2.1 µg/dL and 1.83 µg/dL, respectively, in 2005-2006 (NHMRC, 2014). There are limited studies of individuals who do not live or work near lead mines, smelters, or occupational environments that involve lead exposure. It is considered to be uncommon for individuals in Australia to have BLLs of 10 µg/dL or greater. Further research and monitoring have been recommended by the NHMRC (2015) with respect to BLLs across Australia. Suspected sources of lead exposure in Australia include the historical use of leaded fuels (phased out after 2002), leaded paint, drinking water, consumer products, and environmental exposures (*e.g.* near mining and smelting operations) (NHMRC, 2014).

4.2.2 Jurisdictional Review of Approaches to Address Lead in Soil with Respect to Human Health Risks

At the basis of environmental quality guidelines is the determination of an exposure concentration that is considered to be reasonably safe. With respect to lead, the weight of evidence with regard to what is considered to be a safe level of exposure has evolved over time, with the BLL intervention level (a measure of total lead exposure) being gradually reduced, and environmental quality guidelines shifting downward as well.

A search for grey literature published by agencies and organizations in Canada, the US, New Zealand, Australia, and Europe was completed, with a focus on documents published within the last 10 years. An overview of the findings of this review is provided in Section 4.2.2.1.

More detailed summaries of the current weight of evidence regarding the health effects of lead in humans as summarized in these reports (as they relate to BLL), as well as the available toxicity reference values (TRVs) from various jurisdictions, are provided in Appendix B.

4.2.2.1 Blood Lead Levels and Health Effects – State of the Science

Several recent reviews (within the last 10 years) of the health effects of lead exposure as measured by BLLs were identified from regulatory agencies and organizations with respect to non-occupational exposures. The key findings that emerged from the identified reviews with respect to the current weight of evidence of the health effects of lead, with a focus on BLLs less than 10 µg/dL, are summarized in Table 4-1.

Table 4-1 Key Findings of Jurisdictional Reviews Related to Adverse Health Effects at Blood Lead Levels Less than 10 µg/dL, 2009-2019

Agency/Organization	Key Conclusions
Australia National Health and Medical Research Council (NHMRC, 2014; 2015)	• Adverse health effects in children, particularly cognitive effects (*e.g.*, IQ decrements) are associated with BLLs less than or equal to 10 µg/dL. • BLLs less than 10 µg/dL were associated with adverse behavioural effects in children, delays in sexual maturation or puberty onset in adolescent girls and boys, and increased blood pressure and risk of hypertension in adults and pregnant women.
Agency for Toxic Substances and Disease Registry (ATSDR, 2019)	• Several studies observed significant neurological and behavioural effects in children in association with BLLs less than 5 µg/dL, following prenatal or environmental exposures to low levels of lead. • Adverse immunological, hematological and reproductive effects have been observed in several studies of adults with BLLs of 10 µg/dL and above. • No clear evidence of a threshold or safe level of exposure is evident, and a minimal risk level (MRL) was not derived for lead.
US Center for Disease Control, Advisory Committee on Childhood Lead Poisoning Prevention (ACLPP, 2012)	• Available weight of evidence suggests that BLLs of less than 10 µg/dL are associated with adverse effects on neurocognitive development in children, behavioural effects, cardiovascular, immunological and endocrine effects. These effects appear to be irreversible. • The term 'blood lead level of concern' should no longer be used, as no level of exposure is without concern. • Any child with a BLL above 5 µg/dL is likely exposed to lead *via* one or more pathways. Exposures to lead in homes or child-occupied facilities significantly contribute to BLLs above this level.
United Nations Environment Program (UNEP, 2010)	• No clear threshold for critical lead-induced effects were apparent. • Benchmark-dose models were used (using a non-threshold approach and a level of 1% extra risk) to identify for neurodevelopmental effects in children (0.50 µg/kg-day), chronic kidney disease in adults (0.64 µg/kg-day), and increased systolic blood pressure (1.5 µg/kg-day). • The estimated lead exposure to children ages 0 to 7 years in Europe was found to exceed the $BMDL_{01}$ intake of 0.50 µg/kg-day. It was also concluded that women of reproductive age (20-40 years) had lead intakes associated with some risk of adverse effects to a developing fetus.
Health Canada (2013a)	• Significant evidence of adverse health effects has been observed at BLLs below 10 µg/dL and as low as 1 to 2 µg/dL for developmental neurotoxicity in children. The adverse effects of lead from childhood exposures can persist into late adolescence. • Dose-response modelling does not support the identification of a threshold for developmental neurotoxic effects. For some effect endpoints, namely IQ deficits, the dose-response relationship seems to be curvilinear, with a steeper slope at the lower levels of environmental lead exposures.
Health Canada (2019a)	• A significant number of studies have associated low BLLs (<10 µg/dL) with neurodevelopmental effects in children. In addition, there is evidence that suggests that lead exposure is associated with attention-related deficits, including attention deficit hyperactivity disorder (ADHD) at BLLs less than 5 µg/dL. It is hypothesized that effects on attention may be an underlying cause of deceases in IQ. BLLs as low as 0.8 µg/dL have been associated with neurodevelopmental effects in children (IQ). • There is consistent evidence in humans of delayed puberty in females at BLLs as low as 1.2 µg/dL and suggestive evidence of lead being associated with earlier menopause. • The lowest BLL associated with adverse neurodevelopmental effects cannot be identified; a non-threshold approach using low-dose linear extrapolations should be used to evaluate points of departure for risk estimates.

Table 4-1 Key Findings of Jurisdictional Reviews Related to Adverse Health Effects at Blood Lead Levels Less than 10 µg/dL, 2009-2019

Agency/Organization	Key Conclusions
New Zealand Ministry of Health (NZ MOH, 2012)	• There is evidence of decreases in IQ in children with BLLs less than 10 µg/dL, and also evidence of a lack of reversibility of these effects. However, the NZ management strategy is based on the 10 µg/dL intervention level. At the time, the US CDC had not yet reduced their BLL intervention level to 5 µg/dL.
US National Toxicology Program (NTP, 2012)	• NTP concluded that there is sufficient evidence that BLLs less than 10 µg/dL are associated with adverse neurodevelopmental effects in children (including attention related behavioural problems and decreased cognitive performance), delayed puberty, and decreased postnatal growth. Sufficient evidence was also found of an association between BLLs less than 5 µg/dL with adverse reproductive effects in adult females and reduced fetal growth.
US Environmental Protection Agency (US EPA, 2012)	• The US EPA identified a causal relationship between lead exposure and cognitive function decrements and attention-related behavioural problems in children. At BLLs less than 4 µg/dL, there is no evidence of a threshold for these effects in young children (ages 4 to 11 years). Increases in attention-related problems were found in populations of children ages 7-17 years or young adults ages 19-24 years with prenatal cord or lifetime average mean BLLs between 6.8 and 14 µg/dL. • A causal relationship between lead exposure and cancer, hypertension and coronary heart disease were identified, as well as developmental effects and male reproductive function.
US Environmental Protection Agency (US EPA, 2019)	• Based on internal review by the US EPA and conclusions reached by other US agencies (ACLPP, CDC, NTP), the US EPA proposes to reduce the dust-level hazard standard (DLHS) for lead in floor dust from 40 µg/ft^2 to 10 µg/ft^2, and the DLHS for lead in windowsill dust from 250 µg/ft^2 to 100 µg/ft^2.
World Health Organization (WHO 2010a,b; 2016)	• The most critical health effects are the incidence of neurodevelopmental effects in children. • There is no clear threshold level below which lead is not without adverse effects. • WHO withdrew its previous tolerable weekly intake guideline value for lead on the basis that it was no longer adequate for the protection of cognitive effects in children. There is consistent evidence of adverse effects in children down to and below BLLs of 10 µg/dL. • Low-level lead exposure *in utero* and during childhood in association with BLLs less than 10 µg/dL is associated with adverse neurobehavioral effects in children that can persist into adulthood and be irreversible in nature. These effects may occur at BLLs less than 5 µg/dL. • It is estimated that more than 80% of daily lead intake arises from the ingestion of food, dirt, and dust in most areas. • Adverse effects on infant and child development have been associated with BLLs less than 10 µg/dL (range 6 to 9.5 µg/dL). • Lead-associated decrements in IQ may be markers for other neurobehavioural effects (attention deficit hyperactivity disorder, reading delays, executive dysfunction, fine motor deficits).

4.2.2.2 Available Toxicity Reference Values and Hazard Classifications for Lead

A toxicity reference value (TRV) represents an exposure concentration or a dose of a contaminant that is used as a benchmark for characterizing the risk of the occurrence of an adverse effect. In general, chemicals may be categorized into two groups based on the characteristics of their toxic responses – threshold and non-threshold toxicants. In some instances, chemicals may cause both threshold and non-threshold effects. The concept of a threshold implies that there is a dose or level of exposure below which adverse effects are not expected to occur. For non-threshold chemicals, adverse effects may occur at any level of exposure, with the likelihood or magnitude of the effect increasing with increasing exposure. The development of health-based environmental quality guidelines typically includes consideration of TRVs.

Tabulated summaries of the available TRVs provided by various agencies included in the search are provided within Appendix B. The majority of the regulatory agencies included in this review do not currently list TRVs for lead. This is in part due to the evolution in the understanding of the toxicity of lead, where previously developed TRVs are no longer considered to be applicable and the body of evidence is under review by regulatory agencies. Also, lead exposure is most effectively evaluated by total exposure from all routes combined (*e.g.*, as assessed by biomarkers such as BLLs) as opposed to route-specific approaches (*e.g.*, distinct TRVs for oral and inhalation routes of exposure).

Limits developed by agencies and organizations that evaluate workplace and occupational exposures have not been included in this review to allow for a focus on information relevant to public health. Further, the discussion is also focused on oral-based values rather than inhalation. A select number of recently derived values that are based on evaluating lead on an incremental basis are discussed below.

The Joint Expert Committee on Food Additives and Contaminants (JECFA) of the WHO concluded in 2011 that their previous threshold-based approach to evaluating lead was no longer supported and withdrew their provisional weekly tolerable weekly intake (TWI) (JECFA, 2011). Based on a review of the literature pertaining to lead intake from foods (EFSA, 2010), JECFA (2011) concluded that a chronic lead dose of 0.3 µg/kg-day is associated with a 0.5-point population decrease in IQ in children. It was also noted that a chronic dose of 1.9 µg/kg-day is associated with a population decrease of 3 IQ points, and a 1-point decrement in IQ may reasonably be associated with a BLL of 2 µg/dL. Population-based decrements were considered to be more applicable than individual-based decrements, as an overall shift of the population IQ would result in notable changes in the percentage of individuals within the population with IQ scores below 100 (*i.e.*, equivalent to the population average).

The California Office of Health Hazard Assessment (OEHHA, 2007) has developed a child-specific health guidance value for lead, where an incremental change in blood lead of 1 µg/dL does not necessarily represent a safe exposure level, but represents a lead exposure that would result in a decrease of 1 IQ point. The California Department of Toxic Substance Control has developed a spreadsheet-based model that can be used to estimate BLLs from various routes of exposure, using the child-specific benchmark of an incremental change in blood lead of 1 µg/dL (CDTSC, 2019, CDTSC and HERO, 2019).

Wilson and Richardson (2013) and SNC Lavalin (2012) recommended that based on the chronic lead dose of 0.3 µg/kg-day identified as being associated with a 0.5 decrement in population IQ by JECFA (2011), and the use of 1 IQ point (rather than 0.5 IQ point) as demonstrated by the California OEHHA (2007), that a daily lead dose of 0.6 µg/kg-day is associated with a decrement of 1 IQ point in the population. It is noted by SNC Lavalin (2012) that this value should be considered as a *de minimis* population level effect which could likely never be detected in an individual child. For the protection of women of childbearing age, the *de minimus* dose of 0.6 µg/kg-day based on IQ effects was adjusted based on differences in absorption between adults and children following oral exposure to a value 1.5 µg/kg-day (to ensure cord blood lead concentrations remain below 2.0 µg/dL) (Wilson and Richardson, 2013; SNC Lavalin, 2012). For adults, SNC Lavalin (2012) and Wilson and Richardson (2013) identified that a chronic lead dose of 1.3 µg/kg-day is associated with a population increase in systolic blood pressure (the most sensitive health indicator in non-childbearing adults) of 1 mm mercury (Hg).

One of the most recently derived TRVs arose from a review by Health Canada in support of the revised lead drinking water quality guideline (Health Canada, 2019a). Health Canada (2019a) states that the lowest BLL associated with adverse neurodevelopmental effects cannot be identified, and as a result, a non-threshold approach using low-dose linear extrapolations should be used. Specifically, Health Canada (2019a) identified a benchmark dose (BMD) of 0.4 µg/kg bw-day (representing an external oral dose). This value was obtained from physiologically-based pharmacokinetic (PBPK) and blood lead modelling completed by the EFSA (2010) as part of an assessment of lead in food. Data from Lanphear *et al*. (2005) were analysed by EFSA (2010) and the BLL associated with a 1% response threshold from BMD analysis was identified as 1.2 µg/dL. This 1% response threshold corresponds to a change in population IQ equal to 1 point (after IQ tests were normalized to a mean of 100). The EFSA (2010) then employed blood lead models and determined that a BLL of 1.2 µg/dL was associated with a daily intake ranging from 0.4 to 0.6 µg/kg bw-day (depending on the model used). Health Canada (2019a) notes that it selected the lowest value in the range as a point of departure (POD) for the drinking water guideline derivation, which was based on the US EPA's Integrated Exposure, Uptake, and Biokinetic (IEUBK) model. As a linear extrapolation was used, no uncertainty factors were applied to the POD (Health Canada, 2019a).

Several uncertainties have been noted in the use of IQ scales as a means of evaluating developmental lead neurotoxicity:

- Global tests, like IQ scale tests, may not adequately capture deficits in certain types of brain function as they were not developed for the purposes of neurotoxicity assessment (EFSA, 2010). It has been estimated that there is an approximate error rate resulting in a plus or minus 3-point IQ variability in child IQ tests (Wilson and Richardson, 2013).

- There are numerous potential environmental confounding factors that can also impact IQ in children, including: socioeconomic status (±12 IQ points), parental education (±15 IQ points), attendance at an enriched pre-school (+15 IQ points), breast feeding (+3 to +5 IQ points), iron deficiency (-6 IQ points), elevated iodine in drinking water (-9 IQ points), iodine deficiency (-12 IQ points), methyl mercury exposure resulting in 10 ppm hair concentrations (-2 IQ points), and organophosphate insecticide exposure resulting in urinary levels of 10-times normal levels (-1 to -6 IQ points) (Wilson and Richardson, 2013).

Further, the design of the epidemiological studies that comprise the human evidence for lead toxicity are of varied design (observational, cross-sectional, retrospective or prospective) and can contribute significant variability to the overall dose-response data for lead (EFSA, 2010).

Thus, the use of a benchmark dose based on a 1-point decrement in IQ is associated with a potentially high degree of variability, which must be considered in the interpretation of potential lead exposure risks.

4.2.2.3 Lead in Soils – Comparison of Soil Quality Guidelines Across Jurisdictions

Lead is relatively immobile in soils and has been observed to accumulate in the shallow soil layers, with limited to no degradation (UK DEFRA, 2014). Sections 4.2.2.3.1 to 4.2.2.3.3 describe guidance from various jurisdictions regarding lead soil quality guidelines. Strategies used by jurisdictions to evaluate and mitigate elevated exposures are discussed in Section 4.2.3.

4.2.2.3.1 Soil Quality Guidelines in Canada

The available lead guidelines from Canadian Provinces and Territories were searched and compared. In many instances, Canadian jurisdictions rely on the current guidelines for lead in soil from the CCME. The only identified exceptions included British Columbia and Ontario. Summaries of the available soil quality guidelines for the protection of human health for various land uses from different Canadian jurisdictions that are not based on the CCME guidelines are provided in Table 4-2. Residential soil quality guidelines from British Columbia and Ontario (both 120 µg/g) are both lower than the CCME (1999) value of 140 µg/g. The technical basis of the British Columbia guideline is not clear. Due to the current lack of Provincial regulatory guidance in Ontario surrounding the selection of an appropriate TRV for lead, there is uncertainty regarding the suitability of the Ontario Ministry of the Environment, Conservation, and Parks (MECP) health-based guidelines for lead in soil. Due to these uncertainties, the MECP has deemed it appropriate to compare concentrations of lead in soil to the Ontario background soil concentration of 120 µg/g to provide a qualitative assessment of risks to human health. Under the contaminated sites regulation (Ontario Regulation 153/04), risk assessments are generally required to recommend that capping measures are implemented to prevent direct access to impacted soils when concentrations of lead in surface soils exceed 120 µg/g.

The current soil quality guidelines from the CCME were derived in the mid-1990s by Health Canada and Environment Canada and were considered to be reflective of the science available at the time. The values for the protection of human health are based on a provisional Tolerable Daily Intake (TDI) level, which was derived based on the assumption of a safe threshold level of exposure (which has now been withdrawn, as the weight of evidence indicates that there is no safe threshold). The State of the Science Review on Lead (Health Canada, 2013a) and the recently released revised drinking water guideline for lead (Health Canada, 2019a) both clearly state that adverse health effects have been reported at low levels of lead exposure, equivalent to BLLs less than 5 µg/dL, and even as low 1-2 µg/dL. Health Canada (2013) concluded that there is currently no clear threshold for developmental neurotoxicity. While the CCME (1999) residential soil quality guideline of 140 µg/g has not been revised and thus still remains in effect, it is clear that the current understanding of the health effects of lead has evolved, and that the guideline must be used with a degree of caution until further review is completed. Health Canada (2013b) noted in its summary of risk management actions for lead that the soil quality guidelines for lead are under review. As of 2019, no draft or final documents have been issued outlining any proposed changes.

Table 4-2 Soil Quality Guidelines – Canada			
Agency*	**Value**	**Basis**	**Reference**
British Columbia, Contaminated Sites Regulation	• 120 µg/g (residential, agricultural, wildlands)[a] • 150 µg/g (commercial) • 4,000 µg/g (industrial)	NA	Gov BC, 2019
Canadian Council of Ministers of the Environment (CCME)	• 70 µg/g (agricultural) • 140 µg/g (residential, parkland) • 260 µg/g (commercial) • 600 µg/g (industrial)	Soil and food ingestion (agricultural); soil ingestion (residential/parkland, commercial), off-site migration (industrial)	CCME, 1999
Ontario Ministry of the Environment, Conservation, and Parks (MECP)	• 45 µg/g (agricultural) • 120 µg/g (all property uses other than agricultural)	Ontario background concentration (representative of typical anthropogenic influences)	OMOECC, 2011

NA Information is not available.
* Only jurisdictions that have derived values other than the CCME (1999) values for lead are presented in this Table.
[a] The residential land use standards (both 120 µg/g) are based on the assumption that the use of the land to grow plants for human consumption and to be used as a children's playground, sports field, picnic area or any use by children is prohibited.

As noted previously, doses associated with population-level changes in IQ or systolic blood pressure have been identified and described by Health Canada (2019a), SNC Lavalin (2012), and Wilson and Richardson (2013). To date, the BMD of 0.4 µg/kg-day identified by Health Canada (2019a) as being associated with a change in IQ of 1 point has not been used in the derivation of a soil quality guideline for lead. At this time, Health Canada does not have an available TRV for lead for use at contaminated sites.

As described previously, Wilson and Richardson (2013) identified a *de minimus* daily exposure of 0.6 µg/kg-day as being associated with a 1-point decline in population IQ. Using this value and various assumptions regarding the absorption of lead from ingested soils, receptor characteristics, exposure frequencies, and background exposures, the authors derived soil quality guidelines for different land uses using an approach that is consistent with the CCME guidance for non-threshold contaminants:

- Residential land use (for protection of toddlers): 180 µg/g;
- Commercial land use with play areas (for protection of toddlers): 260 µg/g;
- Commercial land use without play areas (for protection of adults): 8,800 µg/g;
- Industrial land use (for protection of adults): 8,800 µg/g.

The lowest risk-based soil concentration derived by Wilson and Richardson (2013) of 180 µg/g for the residential land use scenario is higher than the current CCME soil quality guideline of 140 µg/g. The work by Wilson and Richardson (2013), based on the concept of an incremental decrease in population IQ identified by JECFA (2011), suggests that the current CCME guidelines are conservative in their protection against detrimental neurotoxic effects in children and blood pressure changes in adults.

4.2.2.3.2 Soil Quality Guidelines in the United States

Given the limited number of Canadian jurisdictions with available guidance for lead in soils, the review was expanded to include agencies in the US. While a comprehensive review of all State soil quality guidelines was beyond the scope of this assessment, a selection of US State agencies was evaluated for available soil quality guidelines for lead. The states identified in Raymond and Brown (2017) as having elevated BLLs were included in this review. The US regions identified as having the greatest number of children with BLLs greater than 10 µg/dL in 2014 included the Eastern North Central region (n=3,157 children, with the States of Illinois and Ohio both having more than 1,000 affected children), the mid-Atlantic Region (n=2,865, with the States of Pennsylvania and New York having more than 1,000 affected children), and New England (n=1,152, with the States of Massachusetts and Connecticut having the most affected children). Children with BLLs >10 µg/dL were identified in other regions of the US as well, but at lower numbers (*e.g*. Western North Central, South Atlantic, Eastern Couth Central, Western South Central, Mountain, and Pacific) (Raymond and Brown, 2017).

While several State governments have developed their own positions on lead in soils, many follow the US EPA soil screening level (SSL) guidance (*e.g*. a residential soil value of 400 µg/g). The US EPA residential SSL value is based on evidence of developmental neurotoxic effects in association with BLLs in the 2 to 8 µg/dL range. The current weight of evidence suggests that adverse neurological effects in children may occur within this BLL range. It is evident from the variation in the available guidelines that some agencies are ahead of others with respect to re-evaluating soil guidelines in association with the weight of evidence regarding lead health effects (US EPA, 2016; 2019). Of those included in this review (Appendix B, Section 1.3), the States that have residential soil quality or remediation guidelines that are lower than the US EPA residential SSL include California and Michigan.

California has derived a residential lead soil guideline of 80 µg/g, and an industrial soil guideline of 320 µg/g (both to be compared with the 95% upper confidence limit of the mean (UCLM) for exposed areas). These values were calculated using the LeadSpread-8 tool developed by California DTSC (2019), which has separate worksheets for evaluating residential and industrial land uses. If a UCLM cannot be determined, it is recommended that the PRG90 values derived by the DTSC (representing soil concentrations that will result in a 90th percentile estimate of a 1 µg/dL incremental BLL increase in a child or a fetus of a pregnant adult worker at an industrial site) be used from LeadSpread8 (CDTSC, 2019). The LeadSpread8 model for children includes a number of exposure parameters that are modifiable, and the model is capable of estimating percentile estimates of BLLs. For adults, LeadSpread8 is a modified version of the US EPA Adult Lead Model (ALM) (CDTSC, 2019).

The Michigan Department of Environmental Quality (MDEQ) has developed a residential clean-up value of 40 µg/g for lead, and a non-residential clean-up value of 90 µg/g. The residential value is based on a BLL of 5 µg/dL or less and is protective of prenatal and postnatal exposures. The non-residential exposure clean-up value of 90 µg/g is intended to be protective of a pregnant worker (MDEQ, 2018).

Additional information regarding the available US soil quality guidelines and associated resources are provided in Appendix B.

4.2.2.3.3 Soil Quality Guidelines - International

Australia and New Zealand have developed guidelines that differentiate between high-density residential and low-density residential, and level of consumption of garden produce. The current Australian soil guidelines for lead are based on the protection of a 10 µg/dL BLL, with the guidelines for residential areas being 300 µg/g. It is apparent that the evidence evaluated by the Australian NHMRC (2014, 2015) is still under review with respect to the modification of the soil quality guidelines. In contrast, the New Zealand Ministry of Health (NZ MOH) released a document outlining environmental case management of lead-exposed individuals. Within this document are several risk-based soil contaminant standards, with the lowest value of 160 µg/g derived for rural residential areas with a higher level of local garden produce consumption (NZ MOH, 2012). Additional information regarding the guidelines from Australia and New Zealand is provided within Appendix B.

A summary of the available European guidelines for lead is presented in Appendix B. In many instances, it was not possible to identify the technical basis of the values, nor is it particularly clear what the differences are between 'warning SSLs' and 'unacceptable SSLs' or how they should be applied. It does appear that some jurisdictions (*e.g.*, Denmark, Germany) have adopted the US EPA SSL of 400 µg/g. Many other European countries have residential soil quality guidelines higher than 400 µg/g. However, some of the more recently derived values are reflective of the conclusion that there is no clear threshold of effect for lead. The United Kingdom Department of Environment Food and Rural Affairs (DEFRA 2014a,b) derived soil quality guidelines for several land uses based on probabilistic modelling that incorporated different exposure parameters, different BLLs (1.6, 3.5 and 5 µg/dL), and different blood lead models (IEUBK, ALM, Carlisle and Wade). A BLL of 3.5 µg/dL was selected as being the most defensible basis for a soil guideline. The DEFRA (2014a,b) soil quality guidelines are as follows:

- 80 µg/g (allotments/community gardens);
- 200 µg/g (residential, with home produce consumption);
- 310 µg/g (residential, no home produce consumption);
- 630 µg/g (parks/open spaces, tracking distance to residential);
- 1,300 µg/g (parks/open spaces, negligible tracking to residential); and,
- 2,300 µg/g (commercial).

The bar graph within Figure 4-1 highlights the variability in the available soil quality guidelines for lead across various jurisdictions. Within this Figure, the current Canadian guidelines are presented in blue, guidelines from various US States in green, New Zealand and Australia in orange, and various European nations in yellow. Several US States appear to have adopted the US EPA SSL of 400 µg/g as a soil quality guideline for lead, as have some European countries. As the US EPA SSL represents a remediation target that is associated with a BLL of 2 to 8 µg/dL, not with an incremental change or a non-threshold approach, use of this value should be interpreted with caution.

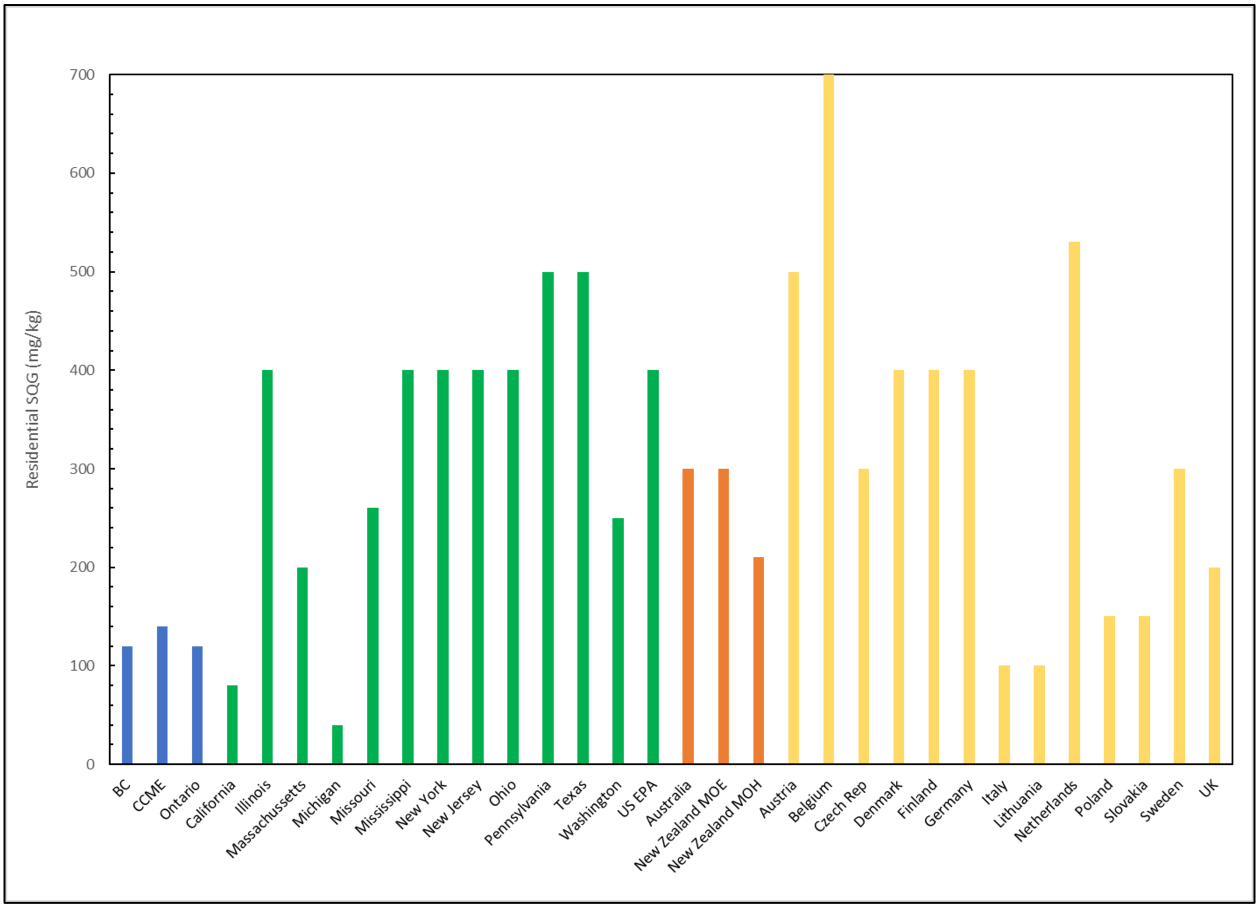


Figure 4-1 Comparison of Available Lead Soil Quality Guidelines

4.2.3 Soil Quality Management and Sampling Strategies for Lead

The influence of deposited lead particles on soil concentrations is typically limited to depths of less than 5 cm due to binding of lead within the soil matrix. Surface soils containing lead pose the greatest hazard to children as they may stick to hands and be ingested through typical hand-to mouth activity. Surface soils may also stick to footwear, toys, and pets and contribute to lead content in household dust (NZ MOH, 2012).

Several strategies for evaluating lead in gardens have been developed by various organizations, and these are presented in Appendix B. Recommended protocols for general soil sampling for the purposes of characterizing lead content are described in Sections 4.2.3.1 to 4.2.3.3.

4.2.3.1 Available Guidance - Canada

Although the CCME outlines generic soil sampling strategies for all contaminants, certain contaminants, such as lead, require different approaches to adequately characterize potential human health risk. In general, current guidance from the CCME (2016) notes that the definition of surface soil includes soils from 0 to 1.5 metres below ground surface (mbgs). However, when assessing direct contact pathways in HHRAs, the most relevant soil depth tends to be less than 5 cm provided that soils are not subjected to gardening, tilling, or excavation (where soils of greater depths may be more applicable) (CCME, 2016).

Toronto Public Health (TPH) (2011, 2012) has developed guidance for assessing soils within urban gardens (including allotment gardens where parcels are cultivated individually, and community gardens where the entire area is tended to collectively by a group of people). Their approach consists of four steps: establishing a level of concern, sampling and testing of soil, interpretation of soil results using certain soil screening values, and risk mitigation. The level of concern of the site (low, medium, high) is based on the findings of a site visit and a review of the site history (current and past use, any requirements necessary under existing contaminated site frameworks), with soil testing recommended for medium or high levels of concern (see Appendix B for additional information).

The TPH developed a short-list of common soil contaminants, of which lead is one, and derived urban gardening soil screening values and a risk management framework based on the concentration in soil relative to these screening values. For lead, the two screening values are 34 µg/g and 340 µg/g. Within the TPH framework for urban soils, this indicates that for soils with lead concentrations less than 34 µg/g, only good gardening practices are recommended (hand washing, produce washing). However, if soil lead concentrations are between 34 µg/g and 340 µg/g, various exposure reduction strategies are suggested (see Appendix B). At soil concentrations above 340 µg/g, it is recommended that in addition to good hygiene practices and dust reduction measures, exposure opportunities be eliminated through the construction of raised bed gardens or containers with the addition of clean soil and organic matter on a regular basis, or restricting crop types to only nut and fruit trees (TPH, 2011).

4.2.3.2 Available Guidance – United States

The US EPA (2003) Superfund program has developed a handbook for evaluating lead-contamination at residential sites. It outlines details regarding recommended hazard communication, education and remediation, as well as sampling protocols.

According to these guidelines, composite samples should be of equal amounts of soil, and be collected at 6-inch (approximately 15 cm) depth intervals (*e.g.*, 0 to 6 inches, 6 to 12 inches, 12 to 18 inches, and 18 to 24 inches). Initial sampling for lead contamination should be completed to at least a depth of 18 inches (45 cm) but less than 24 inches (60 cm). In addition to these composite samples (which define the vertical extent of lead contamination), surface soil composites should be collected from the 0 to 1 inch (0 to 2.54 cm) depth for HHRA purposes from every area within the identified zone of contamination (US EPA, 2003). The top inch of soil "best represents the current exposure to contaminants", while the depth intervals are useful for planning soil remediation (US EPA, 2003).

For residential properties with a total surface area of less than 5,000 ft^2, five-point composite samples should be collected from each of the following areas: front yard, backyard, and side yard. Four-point composite samples should also be collected along the drip zone[1] of each residence. Additionally, discrete soil samples should be collected from play areas, gardens, unpaved driveways, and minimal use areas (crawlspaces, under porches). The locations of each aliquot should be as evenly spaced as possible (US EPA, 2003). For larger properties (> 5,000 ft^2), the property should be divided into four (4) equally sized quadrants (with respect to

[1] Drip zone is the area, typically within 1-2 m of a house, where rainwater may run off structures onto the soil.

surface area), with five-point composites collected from each quadrant, in addition to four-point composites of the drip zone around the building structure (US EPA, 2003). When evaluating the potential for lead exposure at a property, the US EPA (2003) recommends that exposures *via* drinking water and household dust also be evaluated, in addition to outdoor soils.

The US EPA Superfund Program Technical Review Workgroup for Metals and Asbestos (US EPA, 2007) has also released a guidance document for using the IEUBK for lead in soils. The IEUBK is a commonly used model for evaluating BLLs in association with environmental exposures. Within this document (US EPA, 2007), it is noted that soil lead exposure point concentrations used to estimate BLLs should be focused on soil samples collected from the 0 to 1 inch (0 to 2.54 cm) depth range, unless future use scenarios involve potential excavation of deep soils (*e.g.*, basements) in which case additional depths should be added (US EPA, 2007).

A recent memorandum from the US EPA (2016) outlined several recommendations regarding the management of lead in soils, including the following:

- The IEUBK model should be used for determining soil screening levels for residential areas, while the most current version of the Adult Lead Methodology (ALM) model be used for identifying soil screening levels for commercial and industrial sites. It is emphasized that soil screening levels are not remediation goals or clean up levels and should not be used to designate sites. As of May 2019, the SSL for lead is 400 µg/g, a concentration identified by the US EPA as being associated with a hazard index (HI) of 3 for a child, and represents an upper, target risk level (US EPA, 2019).
- Any variations within the models or the incorporation of site-specific bioavailability should be noted. If lead bioavailability is evaluated, the EPA *in vitro bioaccessibility assay* should be consulted, particularly when deriving site-specific clean up levels.
- Multiple sources of lead should be considered at sites with lead impacts, and governments should work together to reduce exposure to lead.
- Resources should be prioritized for the investigation and assessment of lead at federal sites, using a risk-based approach, and in collaboration with local, state and federal agencies.

In 2014, a US EPA guidance document for soils used for gardening was developed based on the potential need for mitigation measures for soils with lead concentrations below the SSL of 400 µg/g. Concentration ranges were derived, taking into consideration:

- Direct ingestion of lead within the matrix of garden produce;
- Ingestion of lead in soil on the surfaces of garden produce;
- Incidental ingestion of soil during gardening; and,
- Incidental ingestion of lead after being tracked into a residence.

Additional information regarding the US EPA (2014b) guidance for gardening is provided in Appendix B.

4.2.3.3 Available Guidance – International

The New Zealand Ministry of Health (NZ MOH) has developed a protocol for lead sampling in various media in relation to environmental case management. With respect to soil sampling, it is recommended that samples be collected from the following areas:

- Outdoor play areas;
- Sand pit/sand boxes;
- Vegetable gardens;
- Areas of soil readily tracked into house;
- Areas most likely to be contaminated (*e.g.* lead paint hot spots);
- Bare soil within one metre of lead-painted surfaces and areas from current or past renovation; and,
- Dusts from paths, patios, or concrete strips adjacent to the house (particularly if located adjacent to past or present lead-based paint hazards).

Hot spots of lead contamination in soils typically occur within 1 to 2 m of the painted surface, although past dumping or burning of building materials containing lead-based paints can occur at distances from the structure. Exterior dusts may also be impacted with lead from these sources (NZ MOH, 2012).

The NZ MOH (2012) recommends that multiple samples should be collected for each location and made into a composite. Unless core samples are taken and analyzed, all samples should be taken from the top 3 to 5 cm of soil. However, older soil layers of lead may be buried beneath the top 5 cm of lead. It is recommended that core samples be checked for lead variability at various depths (NZ MOH, 2012).

4.2.4 Blood Lead Intervention Strategies

Blood lead is the most widely used biomarker of short-term lead exposure and is used to identify individuals with elevated exposures. The US CDC's current recommended intervention level is 5 µg/dL (US CDC, 2019). In adults, the measurement of lead in bone by X-ray fluorescence (XRF) is used for a more accurate estimate of long-term exposures (ATSDR, 2019).

Lead exposure is an issue that affects all countries and represents a significant public health challenge. Brief summaries of strategies used by various governments to address public health concerns are outlined below, along with examples of existing approaches used by different agencies for the surveillance of lead. The approaches identified in a review of available documents from jurisdictions in Canada, the US, and international agencies are summarized in Sections 4.2.4.1 to 4.2.4.3.

4.2.4.1 Approaches to Blood Lead Intervention in Canada

In 2013, Health Canada completed a comprehensive review of the most recent state of the science on lead; however, it has not updated the blood lead intervention level of 10 µg/dL since that time. The supporting documentation for the recently revised drinking water guideline for lead developed by Health Canada (2019a) noted that adverse neurodevelopmental effects in children have been reported in association with BLLs less than 5 µg/dL.

No information regarding mandatory blood lead reporting and tracking was identified during this review for Canadian jurisdictions, other than Quebec. This is consistent with a presentation made by Public Health Ontario in 2016, where it is noted that Quebec is the only province with such programs for non-occupational exposures (Public Health Ontario, 2017). It is also noted within a jurisdictional review completed as part of a study by the City of Hamilton (2011b) that this is due to the relative infrequent reporting of lead intoxication in Canada and cost-benefit implications.

In Quebec, lead exposure is considered to be a reportable disease of chemical origin. Physicians are required to report the results to regional public health authorities in order to help identify and reduce sources of exposure (Government of Quebec, 2018). As noted previously, blood lead data are collected along with various other details across Canada as part of the Canadian Health Measures Survey assessment. However, the intent of this sampling is to determine baseline levels of chemicals in the Canadian population, to aid in the setting of future priorities, and to evaluate the effectiveness of health and environmental risk management activities (Health Canada, 2019b).

The British Columbia CDC (BC CDC, 2014) is considering making the reporting of blood lead analysis mandatory for all laboratories operating in the province as part of the notifiable disease provisions outlined in the Public Health Act. In a recently released document, the British Columbia CDC (2014) notes that making reporting of blood lead analysis mandatory would have the following benefits:

- Promote understanding of the circumstances under which blood lead tests in the province are being requested;
- Permit analysis of patterns in blood lead testing frequencies by age, time and area, and also in patterns of atypically high levels of lead in blood; and,
- To identify individuals who require further assessment and exposure management, and to help identify other individuals with atypical exposures.

Some recommendations that were made by the British Columbia CDC (2014) with respect to lead surveillance activities included:

- Evaluation of historical blood lead data from the same laboratories included in the study (specifically 2005-2008 and after 2010) to evaluate trends over time;
- To examine the blood lead data with a finer level of detail with respect to geographical locations, particularly within the region with the greater number of elevated BLLs (*e.g.*, Interior Health region);
- To incorporate environmental monitoring data in effort to identify areas where people may be more likely to be exposed to lead in the environment, and to compare these environmental data with blood lead data;

- Incorporate socio-demographic data with blood lead data to identify potential vulnerabilities and risk factors;
- To explore linkages with other data sources, including the establishment of an administrative cohort using health services data utilization where BLLs are elevated, in order to evaluate the burden of lead exposure on provincial health care services;
- Compare blood lead test results and population testing rates between billing sources (*e.g.*, provincial health insurance vs. occupational programs vs. existing targeted screening programs);
- Compare results with the British Columbia Drug and Poison Information Centre Data to examine BLLs in specific areas where calls to the Centre originate; and,
- To follow up on elevated BLLs and mitigate exposure.

Blood lead monitoring within municipalities is conducted in response to concerns from public health personnel. A complete search of all urban studies of blood lead was not completed. However, certain recent reports of potential interest to the Government of Manitoba were identified in other jurisdictions (Sections 4.2.3.2 and 4.2.3.3). In addition, several case studies conducted in urban and industrial areas that included blood lead monitoring and various types of interventions are described in Section 4.2.5.

4.2.4.2 Approaches to Blood Lead Intervention in the United States

In December 2018, the US issued an Executive Order accompanied by an action plan regarding the reduction of childhood lead exposures and associated health impacts (Gov US, 2018). It is intended to serve as a 'blueprint' for exposure reduction and requires collaboration between all levels of government as well as property owners, businesses and parents. The action plan document was authored by a Presidential Task Force following an in-depth stakeholder consultation effort. Four (4) primary goals were set by the group (additional information regarding these goals are provided in Appendix B):

1. Reduce children's exposure to lead sources;
2. Identify lead-exposed children and improve their health outcomes;
3. Communicate more effectively with stakeholders, promoting lead prevention and monitoring education; and,
4. Support and conduct critical research to inform efforts to reduce lead exposures and related health risks.

In April 2019, a status report on the Federal Action Plan was released, outlining the various actions that have taken place in relation to each goal. Revisions to the existing dust level standards for lead were announced on June 21, 2019 (*i.e.*, reduce the dust-level hazard standard (DLHS) for lead in floor dust from 40 µg/ft^2 to 10 µg/ft^2, and the DLHS for lead in windowsill dust from 250 µg/ft^2 to 100 µg/ft^2 (Gov US, 2019).

The US CDC Childhood Lead Poisoning Prevention Program (CLPPP) recommended that all children be tested at least once for blood lead, which resulted in the analysis of data provided voluntarily by several different State governments. In 2012, the ACCLP recommended that all children who have a BLL of 5 µg/dL or more undergo further monitoring and intervention (ACCLP, 2012). It was recommended that historical information on where children with elevated BLLs live or have lived is shared with authorities so that resources for environmental testing and evaluation can be deployed. The CDC (2019) provides a summary of actions for various BLLs in children (Table 4-3). A key component of effective BLL surveillance is the mandatory requirement for laboratories to report all BLL results to state health departments. Also important are intensive efforts to identify and provide services to children with elevated BLLs, such as appropriate medical, nutritional, environmental and educational interventions. Primary prevention strategies such as controlling or eliminating sources of lead are noted to be the only effective means of preventing adverse neurodevelopmental and behavioural effects associated with lead exposure (ACCLP, 2012). It was recommended that children with cognitive or behavioural problems associated with lead exposure receive support that is aimed at improving academic performance.

Table 4-3 Summary of Current US CDC Recommendations for Follow-up and Case Management of Children Based on Confirmed Blood Lead Levels

Confirmed Blood Lead Level[a,b]					
< 5 µg/dL	**5 – 9 µg/dL**	**10 – 19 µg/dL**	**20-44 µg/dL**	**45 – 69 µg/dL**	**≥70 µg/dL**
Routine assessment of nutritional and developmental milestones Anticipatory guidance about common sources of lead exposure Follow up blood lead testing at recommended intervals based on child's age[c].	Routine assessment of nutritional and developmental milestones Environmental assessment of detailed history to identify potential sources of lead exposure. Nutritional counselling related to calcium and iron intake. Follow up blood lead testing at recommended intervals based on child's age[c].	Routine assessment of nutritional and developmental milestones. Environmental assessment of detailed history and environmental investigation including home visit to identify potential sources of lead exposure. Nutritional counselling related to calcium and iron intake, consider lab work to evaluate iron status. Follow-up blood lead monitoring at recommended intervals[c].	Complete medical history and physical exam. Neurodevelopmental assessment. Environmental investigation of the home and lead hazard reduction. Lab work for iron status, hemoglobin or hematocrit. Abdominal X-ray (with bowel decontamination if indicated). Follow up blood lead monitoring at recommended intervals[c].	Complete medical history and physical exam. Complete neurological exam, including neuro-developmental assessment. Environmental investigation of the home and lead hazard reduction. Lab work for iron status, hemoglobin or hematocrit. Abdominal X-ray (with bowel decontamination if indicated).	Hospitalization, commencement of chelation therapy in consultation with a medical toxicologist or a pediatric environmental health speciality unit. Proceed with additional actions according to interventions for the 45-69 µg/dL category. Lab work for iron status, hemoglobin or hematocrit.

a Confirmed BLL is defined by the CDC as being one venous blood test or two capillary blood lead tests drawn within 12-weeks of each other (CDC, 2019).

b Recommended schedules for obtaining a confirmatory venous sample: BLL 5-9 µg/dL – 1 to 3 months; BLL10-44 µg/dL – 1-week to 1-month; BLL 45 – 59 µg/dL – 48-hours; BLL 60-69 µg/dL – 24-hours; BLL > 70 urgently (CDC, 2019).

c Recommended schedules for follow up blood testing: BLL 5-9 µg/dL –6 to 9 months; BLL 10-19 µg/dL – 3 to 6 months; BLL 20-24 – 1 to 3 months; BLL 25 – 44 – 1-month; > 45 µg/dL – as soon as possible. Due to seasonal variation in BLL in colder climates, greater exposure potential in warm months may require more frequent follow-up samples. For new patients, it may be of value to repeat blood tests within 1-month for BLL < 25 µg/dL but > 5 µg/dL to ensure that BLL is not rising (CDC, 2019).

Several US States have implemented their own BLL testing programs. In California, testing of children is not mandatory, however, the reporting of all blood lead results (for adults and children) by laboratories (along with personal details) is mandatory. California has established a Childhood Lead Poisoning Prevention Program, which is charged with compiling all test data, and analyzing this information with respect to prevalence, causes, and geographic occurrence of elevated BLLs (Leg Cal, 2019a). It is also required that every health care service plan that provides group coverage for hospital, medical, or surgical expenses must offer comprehensive preventative care for children 17 years and under, including blood lead screening for children at risk of lead poisoning (Leg Cal, 2019b). In addition, the State has requirements for lead-safe housing, accredited service providers for lead testing and abatement, occupational standards, and standards for the presence of lead in plumbing, food and consumer products (CDPH, 2018). As noted previously, the California OEHHA (2007) has developed a child-specific health guidance value for lead – an incremental change in blood lead of 1 µg/dL in relation to exposures from a specific location, which is used as an alternative to the 10 µg/dL used previously. However, a change in blood lead of 1 µg/dL does not necessarily represent a safe exposure level, but rather is based on a lead exposure that would result in a decrease of 1 IQ point (OEHHA, 2007). The California Department of Toxic Substance Control has developed a spreadsheet-based model that can be used to estimate BLLs from various routes of exposure. Using the child-specific benchmark of an incremental change in blood lead of 1 µg/dL, risk-based soil quality guidelines were derived (CDTSC, 2019, CDTSC and HERO, 2019).

In the State of New York, public health law and regulations require that all health care providers test all children 1 year of age for blood lead, and again at 2 years of age. Using standardized questionnaires, all health care providers must assess children ages 6 months to 6 years at every routine visit for lead exposure potential (NYSDOH, 2019). Additional blood testing is conducted if there are positive responses regarding potential lead exposure sources. It was also recommended that all foreign-born children less than 16 years of age be tested upon arrival in the US and again during a period of three to six months after they obtain permanent residency status. In the event that lead exposure is suspected, regardless of the answers to the questionnaire, blood lead testing should be completed. For children with BLLs between 5 and 9 µg/dL, additional testing within three to six months is recommended, especially if the child is less than 2 years of age, or if BLLs have increased or the child is considered to be high-risk. The child should also be monitored for developmental and behavioural problems. For children with BLLs above 10 µg/dL, various additional interventions are recommended, including exposure assessment, nutritional assessment, educational efforts, or hospitalization (NYSDOH, 2019).

In Michigan, in response to a high rate of lead toxicity cases in children, a Plan of Action was developed by a Commission and presented to the legislature (CLPPCC, 2007; 2009). The first priority identified by the Michigan Childhood Lead Poisoning Prevention and Control Commission was to eliminate lead hazards from all Michigan homes and daycares used by children under the age of 6 years. The emphasis of this effort was on lead paint remediation in buildings constructed before 1978. A recommendation was made for all children residing in ZIP codes with a history of high BLLs to be tested on a mandatory basis (CLPPCC, 2007). By 2009, the number of BLL tests in children increased by over 1,000, however, testing decreased in some of the high-risk communities (MCLPPCC, 2007). Blood lead data for children in Michigan are available for those covered by Medicaid, as children in this program must be tested for lead exposure at ages 1 or 2 years, or 3 through 5 years (Gomez *et al*., 2019).

In light of a recent drinking water contamination event in the City of Flint, Michigan[2], BLLs of children are being closely evaluated and the Governor of Michigan created the Child Lead Poisoning Elimination Board by way of an Executive Order in 2016 to develop a 'roadmap' to eliminate childhood lead poisoning (State of Michigan, 2016). A study by Gomez *et al*. (2019) determined that between 2006 and 2016, there was an overall 72.9% decrease in the percentage of children with BLLs greater than 5.0 µg/dL, suggesting that public health efforts to reduce lead exposure had been successful. However, a key finding of the Child Lead Poisoning Elimination Board was that overall blood lead screening rates for children in the State were low, and the Michigan Department of Health and Human Services (MDHHS) lacked the infrastructure and funding to adequately manage workload and follow-up services. The Board made several recommendations to the State Governor regarding improved childhood lead management including (but not limited to) improved testing rates for all children ages 9 to 12 months and 24 to 36 months, reporting of all BLLs greater than 5 µg/dL, improved communication, coordination and information management between agencies, and promotion of public education to the public and health care providers (State of Michigan, 2016). It is not clear at this time how many of the recommendations have been adopted by the State Government as law or policy.

The State of Alaska recommends and provides universal blood testing to all Medicaid-eligible children in the State, and all blood lead test results must be reported to the Alaska Section of Epidemiology which monitors test results in a database. Follow-up telephone interviews are also completed as required to identify exposure sources. These measures were implemented to help identify at-risk children and exposure sources within communities (Bressler *et al*., 2019). For example, between 2011 and 2018, it was identified that the exposure sources associated with elevated BLLs in Alaska (children ages 0-72 months) included: parental occupation, food and water consumption, pre-1978 housing or current home renovations, pica or mouthing behaviours, and exposure to fishing weights, lead ammunition or firearms and household objects (Bressler *et al*., 2019).

All children within the State of Maine who are eligible for Medicaid are required to have a blood lead test (venous or capillary) between the ages of 1 and 2 years, and children without Medicaid are required to have blood testing if they are identified as being at risk. All children with BLLs of 5 µg/dL or above receive a phone call from the Maine Childhood Lead Poisoning Prevention Unit to collect additional information, and to set up licenced environmental lead inspections of homes. Lead paint-related dust hazards were identified in 79% of the homes with children who had elevated BLLs in the State between September 2016 and March 2018. For BLLs above 10 µg/dL, exposure was not clearly related to one source, but identifiable lead sources were noted in these households. In children with BLLs between 5 and 9 µg/dL, the lead hazards were found to be generally less severe and fewer in number, and consisted primarily of dust-related hazards (Cluett *et al*., 2019).

In Washington State, the Governor recently made a Directive to the Department of Health with several recommendations for improvement based on the recognition of there being no safe level of lead exposure (WSDOH, 2016 – see Appendix B for additional details). As of October 2018, it is recommended by the Washington State Department of Health (WSDOH) that all healthcare

[2] Approximately 140,000 individuals within the City of Flint Michigan were exposed to lead and other contaminants in drinking water as a result of a change in water source without proper corrosion control treatment to prevent lead release. The Flint crisis triggered the involvement of the US government, and follow-up activities by multiple levels of government. The situation also highlighted the necessity of risk communication, environmental health infrastructure, improved surveillance and primary prevention (Ruckart *et al*., 2019).

providers educate the parents of children ages 6 months to 6 years regarding lead exposure during routine check-ups and complete blood lead testing at 12 and 24 months of age based on risk level (additional information within Appendix B). In the event of a positive response, or where the answer was not known, it was recommended that blood lead testing be completed. Testing might also be recommended if parents have concerns, if children live within a kilometer of an airport or lead-emitting industry or orchard, if a child has pica behaviour, or if a child is affected by neurodevelopmental disabilities (such as autism, attention-deficit hyperactivity disorder or learning delays) (WSDOH, 2018). Follow-up testing is recommended after 1 year of the first test for children with BLLs less than 5 µg/dL, within 1 to 3 months if the first result is between 5 and 14 µg/dL, within 1 to 4 weeks if between 15 to 44 µg/dL, and within 48 hours if the BLL was greater than 45 µg/dL (WSDOH, 2018). Venous samples are preferred over capillary samples, unless adequate care is taken to clean and prepare the finger before testing. Initial samples that are capillary should be followed up with venous samples (WSDOH, 2018).

4.2.4.3 Approaches to Blood Lead Intervention - International

Outside the US, the approach for intervention varies. In New South Wales, Queensland, Tasmania and Victoria, laboratories must notify public health authorities when BLLs exceed 10 µg/dL. Elevated BLLs were not considered to be notifiable conditions within the Australian Capital Territory, the Northern Territory or South Australia as of the 2015 NHMRC report. However, in the event that an elevated BLL is identified by a doctor, referral to a public health practitioner or environmental health office is recommended in these areas. In Western Australia, the approach is less clear, with medical practitioners only having to notify public health authorities in cases of 'lead poisoning' (NHMRC, 2015).

From the available information, blood lead monitoring is not mandatory in the United Kingdom or mainland Europe.

4.2.5 Case Studies of Lead in Urban and Industrial Areas

Several case studies where historical or current lead emissions have been identified in association with elevated BLLs in children are described in this Section, with an aim of identifying the most effective strategies used to mitigate lead exposure to children. Focus was given to communities in Canada, the United States, or Australia.

4.2.5.1 Flin Flon, Manitoba

The Hudson Bay Mining and Smelting Co. (HBMS) operated a fully functional mine and base metal smelting complex in Flin Flon, Manitoba commencing in the 1930s. As a result of historical activities at the HBMS facility, various government agencies and independent researchers completed numerous studies considering the content of smelter-related metals in the environment within the surrounding area. In August 2006, Manitoba Conservation conducted soil sampling to determine the concentration and potential distribution of metals and other elements in the surface soils of Flin Flon and the adjacent community of Creighton, Saskatchewan. The Manitoba Conservation report "*Concentrations of Metals and Other Elements in Surface Soils of Flin Flon, Manitoba and Creighton, Saskatchewan, 2006*" was published in July 2007 (Manitoba Conservation, 2007). This report recommended further study to better understand potential health risks for people living in the Flin Flon Area related to the HBMS smelter emissions. The Flin Flon Soils Study arose out of this recommendation.

The Flin Flon Soils Study, initiated by HBMS in July 2007, included several components designed to better understand the nature of facility emissions and soil conditions in the area, and to determine if exposure to these metals and elements posed an increased health risks to residents and visitors. The components of the study included:

- supplemental environmental data collection (residential soil, indoor dust, drinking water, ambient air, fish, surface water, sediment, blue berries, snow);
- an extensive HHRA conducted in 2008; and,
- an evaluation of children's exposure (through biomonitoring) to lead, inorganic arsenic, and inorganic mercury conducted during Fall 2009. Blood lead data from this study are provided in Table 4-4.

Based on the findings from the HHRA and the evaluation of exposure, recommendations were made in 2010 to undertake efforts to reduce children's exposure to lead. Based on these recommendations, further efforts were made by HBMS and governmental authorities. This included a public health awareness campaign that targeted (i) parents and children to improve the frequency and quality of handwashing among children; and, (ii) homeowners and contractors undertaking renovations to ensure proper training, procedures and clean-up (including making high-efficiency particulate air (HEPA) vacuums available for rental/borrowing as needed). Other efforts included continuation of an HBMS program of progressive remediation and re-vegetation of the area in and around the Flin Flon metallurgical complex, as well as a sustained effort by HBMS to continue with operating practices and procedures aimed at minimizing dust emissions from the Flin Flon Metallurgical Complex. These reduction efforts were emphasized in areas such as the metallurgical operations, tailings facility, *etc*. HBMS continued to make other environmental improvements within its operations, such as the paving of in-plant roads and material handling upgrades to help improve ambient air quality. There were operational changes in the three (3) years following the original exposure study, including the closing of the Copper Smelter in 2010. A follow-up blood lead monitoring program was conducted in 2012 to determine the extent to which the community BLLs of children living in the Flin Flon Area have changed since the original exposure study. Results of this study are provided in Table 4-4.

Table 4-4 Comparison of Child Blood Lead Levels in Flin Flon, Manitoba and Creighton Saskatchewan in 2009 and 2012 (Intrinsik, 2013)

Characteristics	2009			2012			Change in Mean (by µg/dL)
	Geometric mean (µg/dL)	N	Std	Geometric mean (µg/dL)	N	Std	
All	2.73	202	1.84	1.41	118	1.93	-1.32
Sex							
Female	2.34	93	1.63	1.23	62	1.86	-1.11
Male	3.12	109	1.96	1.65	56	1.95	-1.47
Age at Interview							
Less than 24 months (age 1)	2.32	48	1.94	1.11	30	2.17	-1.21
24 to 35.99 months (age 2)	3.08	33	1.52	1.98	17	1.64	-1.10
36 to 47.99 months (age 3)	2.24	23	1.67	1.57	10	1.70	-0.68

Table 4-4	Comparison of Child Blood Lead Levels in Flin Flon, Manitoba and Creighton Saskatchewan in 2009 and 2012 (Intrinsik, 2013)						
Characteristics	**2009**			**2012**			**Change in Mean (by µg/dL)**
	Geometric mean (µg/dL)	**N**	**Std**	**Geometric mean (µg/dL)**	**N**	**Std**	
48 to 59.99 months (age 4)	2.52	43	1.85	1.43	19	1.52	-1.08
60 to 71.99 months (age 5)	2.89	28	1.72	1.43	24	1.68	-1.46
72 to 83.99 months (age 6)	4.04	27	1.98	1.43	18	2.44	-2.61
Region of Residence							
East Flin Flon	2.29	84	1.83	1.32	75	2.03	-0.98
West Flin Flon	3.64	43	1.67	2.11	18	1.50	-1.53
Channing	1.99	12	1.67	--	--	---	--
Creighton	3.02	63	1.84	1.30	24	1.75	-1.72

Comparison of the Flin Flon datasets from 2009 and 2012 revealed the following:

- All metrics of blood lead were lower in 2012 relative to 2009:
    - Statistically significant decreases were noted across all subgroups evaluated, including age, gender and region;
    - Geometric means, upper percentile and maximum BLLs were lower; and,
    - The number of children with BLLs greater than 5 µg/dL decreased.
- Mean and upper percentile BLLs for all subgroups in the 2012 dataset were less than the intervention level established by CDC (5 µg/dL);
- The geometric mean BLL (1.41 µg/dL) of all children studied in the Flin Flon area in 2012 was higher than the national (Canadian) geometric means for children in the 3-5 year and 6-11 year age groups (geometric means of 0.77 µg/dL and 0.71 µg/dL, respectively). Similarly, the overall geometric mean in the Flin Flon area of 1.41 µg/dL was higher than comparable values from the US NHANES (2011-2012) data, where the geometric mean BLLs for children ages 1-5 years and 6-11 years were 0.970 and 0.681 µg/dL, respectively.
- Other than housing age, personal factors were not associated with children's lead exposure levels in 2012. This included knowledge of previously implemented intervention strategies (the hand washing campaign). This indicated limited impact of these personal factors and intervention strategies.
- Environmental factors were found to be poor indicators of BLL. It is likely that additional factors commonly linked to BLL in children, such as socioeconomic status, represent a greater influence on BLLs in children in the Flin Flon Area.

Consideration of the Flin Flon dataset and the available regulatory and scientific information regarding lead intervention levels and strategies led to the conclusion that operational changes to the HBMS facility had resulted in a significant decrease in the levels of lead exposure for children in the Flin Flon Area (Intrinsik, 2013).

4.2.5.2 Trail, British Columbia

A major lead and zinc smelting facility has been located in the City of Trail, British Columbia for over 100 years. In 1975, elevated BLLs were identified in children. A follow-up study in 1989 noted that, while BLLs had declined since 1975, over 39% of the children within the community presented BLLs above 15 µg/dL. These findings resulted in the formation of a Trail Community Lead Task Force (TCLTF) in 1990, a group made up of representatives from provincial and municipal governments, industry, the general population, the school district, environmental groups, and the United Steelworkers of America. This task force was funded by the British Columbia Ministries of the Environment and Health, Cominco Ltd. (now Teck), and the City of Trail (TCLTF, 2001).

The report entitled "*Identification, Evaluation and Selection of Remedial Options*" was finalized in 2001 and represented the conclusion of more than a dozen detailed reports and four peer-reviewed journal articles written by staff and consultants of the Trail Community Lead Task Force (TCLTF, 2001). This report examined the sources and pathways of lead exposure, community blood lead trends, and provided recommendations for remedial programs.
Lead sampling inside and outside residential properties was commenced in the mid-1990s by the Task Force. Lead concentrations in house dust and soil were found to be generally higher in homes closer to the smelter. There was considerable evidence that the lead in air was predominantly from current stack and fugitive emissions, rather than re-entrainment of historically deposited emissions. The tracking-in of dust was a dominant mechanism for transferring lead into houses, where the rate of track-in may be at least four times greater than settling from air (TCLTF, 2001).

Interior house dust and yard soil were the dominant sources of lead exposure for children. For children less than 18 months of age, interior house dust was the most significant source of exposure to lead. For children aged 18 to 35 months, time spent outdoors on a daily basis and lead concentrations in yard soil were significant predictors of their BLLs. The ingestion of dust and soil was a greater contributor to BLLs than the inhalation of airborne lead. Drinking water, locally grown produce, and lead paint did not appear to be significant sources of lead exposure (TCLTF, 2001). Blood lead levels did not appear to differ between children with parents that worked in a lead industry and those children with parents that did not; however, children with parents who smoked cigarettes or had a dog or cat as a pet, tended to have higher BLLs.

A new lead smelter using improved technology was installed in May 1997 and reduced lead emissions from the stacks by approximately 75%. Since the new smelter commenced operation, the average outdoor dustfall lead loading, the average street dust lead loading, and the indoor dustfall lead loading all decreased by 50%. After 1997, the average lead concentration in street dust decreased by approximately 20% (TCLTF, 2001).

From 1989 to 1996, the average BLLs of children aged 6 months to 4 years (being tested for the first time) declined at an average rate of 0.6 µg/dL/year, from 14.8 µg/dL to 11.0 µg/dL. From 1996 to 1999, the average BLL of children tested for the first time fell by 54%, from 11.0 µg/dL to 5.1 µg/dL. The average annual rate of decline during this period was 1.9 µg/dL/year and appeared to be attributable to the replacement of the old lead smelter in May 1997. In 2000, the average BLL of children (being tested for the first time) increased to 6.3 µg/dL, which appeared to be related to weather conditions (TCLTF, 2001).

The recommendations from the Trail Community Lead Task Force (TCLTF, 2001) were for the following actions:

- Public Health Unit (Kootenay Boundary Community Health Services Society): Continue blood lead testing of children 6 to 36 months of age, continue counseling and services for families with children who have elevated, or risk of elevated BLLs, and continue community and pre-school education programs about preventing and reducing exposure to lead;
- Cominco (now Teck): Pursue further reductions in facility emissions with increased reporting to the public on plans and progress, continue greening around the Cominco property and the community, continue environmental monitoring of air and street dust, continue addressing soil on a case-by-case basis, and implement a new program to advise and assist people that are doing excavation, construction, demolition or renovation;
- City of Trail: Flush and sweep the streets, continue dust control on alleys and other unpaved areas, and continue greening of bare public areas; and,
- Establishment of a Trail Health and Environment Committee to monitor, coordinate, and advise on the implementation of the Task Force's recommendations.

The Trail Area Health & Environment Program (THEP) is a continuous adaptive management program that is managed by the Trail Area Health and Environment Committee (THEC), a sub-Committee of the City of Trail, and is comprised of community members, Teck, British Columbia Interior Health, and the British Columbia Ministry of the Environment. Public consultation exercises were completed in 2000, 2010 and 2016 with respect to the goals of the program.

The THEP includes several program areas, with an overall aim of reducing childhood BLLs:

1. Air Quality – includes initiatives to reduce stack, fugitive and dust emissions from the Teck Trail operations, dust control within the community (*e.g.*, street sweeping, dust suppressant), on-going air quality monitoring and reporting.
2. Family Health – provides information and education for parents on preventing lead exposure, and in-home visits for families with children under 12 months and expectant families, blood lead testing for children ages 6 to 36 months of age, and support for families with children above the typical BLL range. All programs are free and voluntary (THEP, 2019b).
3. Home & Garden – includes in-home visits to expectant families and families with children less than 36 months of age, including soil testing and recommendations on reducing potential lead exposure, soil management plan (including replacement of residential soil with lead concentrations above 5,000 µg/g or vegetable garden soil with concentrations above 1,000 µg/g) (THEP, 2019b,c).
4. Eco-System Management – collaborative approach within the Lower Columbia region to assess, rehabilitate, conserve and enhance terrestrial ecosystems. This program included remediation and risk management of potential ecological risks from lead exposure (THEP, 2019d).
5. Property Development Program – includes a Lead Safe Home Renovation plan, where any homeowner or tenant in Trail or Rivervale or in the Lower Columbia Region with pre-

1976 homes can obtain free equipment, supplies and information regarding safe practices and waste disposal (THEP, 2019c).

Feedback from the most recent public consultation regarding THEP was collected during September 2016 (THEP, 2016). The draft program goals presented during the 2016 consultation process for activities until 2020 included:

- To obtain an average (geometric mean) BLL of 3.5 µg/dL or lower for children ages 6 to 36 months in the communities of Trail and Rivervale by 2020;
- To have at least 95% of BLLs in children ages 6 to 36 months below 10 µg/dL by 2020;
- To achieve an annual average lead concentration in air (as measured in total suspended particulate) in the community of 0.2 µg/m^3, with continuous improvement, by 2020;
- To have at least 75% of children ages 6 to 36 months in the communities in Trail and Rivervale participate in voluntary blood lead testing clinics each year;
- To have continuous improvements made in the number of home renovation service providers in Trail and Rivervale, with renovators of pre-1976 homes through the Trail area using the Lead Safe renovation free and voluntary program; and,
- To have at least 95% participation by eligible families in the 'Healthy Families Healthy Homes' voluntary program each year.

A total of 258 residents in the Trail area participated in the 2016 consultation program, which included a 30-question survey administered *via* SMS text message, a website, or on paper. Of those surveyed, 80% fully supported the draft THEP goals listed above. Approximately 79% of respondents supported the Family Health Program goals of having an average BLL of 3.5 µg/dL or less, and the blood lead clinic participation goal. Overall, 83% of the respondents supported the lead air quality goals, 85% supported maintaining the residential soil testing program priorities, 78% supported the established action levels for soil remediation with others recommending that these action levels be lower, and 83% fully supported improvement to participation in the Lead Safe renovation program. The 2016 consultation revealed that increase in participation in THEP occurred between 2010 and 2016, and that many individuals had positive experiences with the Family Health and Home and Garden programs.

With respect to the effectiveness of the various intervention programs on BLLs, the average BLL in the affected areas had decreased since the commencement of the THEP after the release of the task force report in 2001. A map of the three (3) sampling areas included in the follow-up BLL monitoring is presented in Figure 4-2.

The greatest decreases in BLLs appear to have occurred over the 1990s, a period which included the phase-out of leaded gasoline in Canada (1989) and the installation of the updated smelter (1997), with some further reductions evident in the areas closest to the smelter (areas 2 and 3, representing the City of Trail and community of Riverdale) following the implementation of recommendations from the TCLTF (2001) report, Figure 4-3.

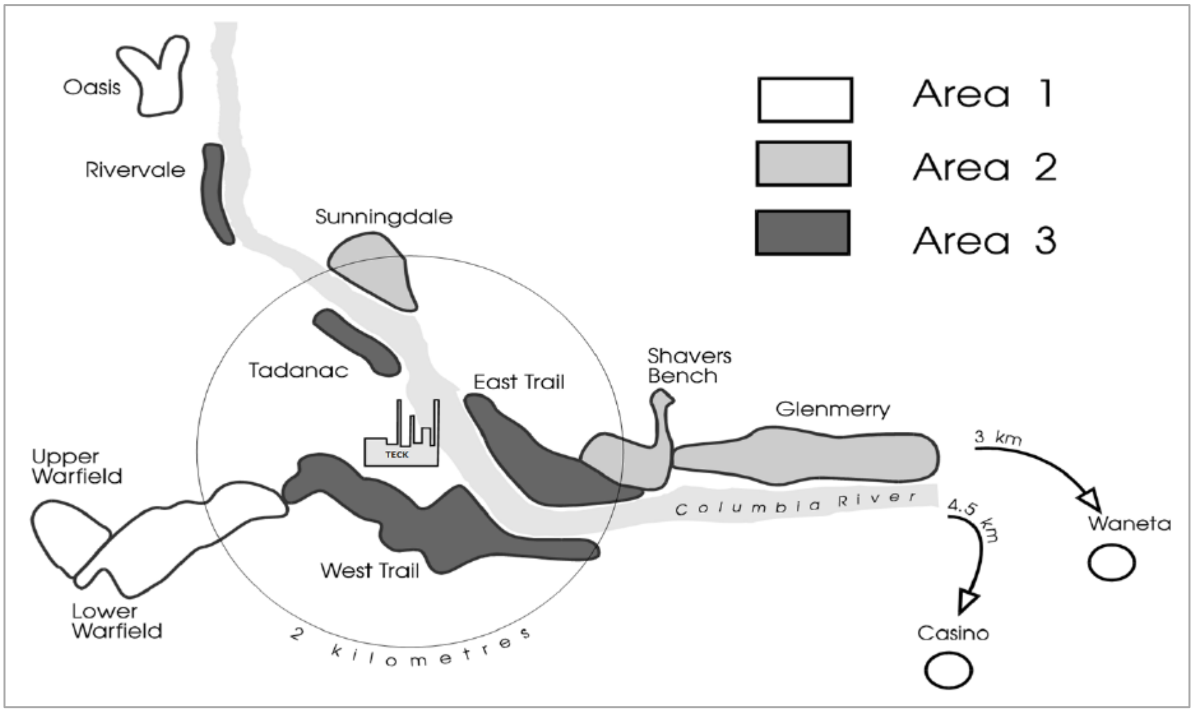


Figure 4-2 Childhood Blood Lead Sampling Program Areas (Interior Health, 2019)

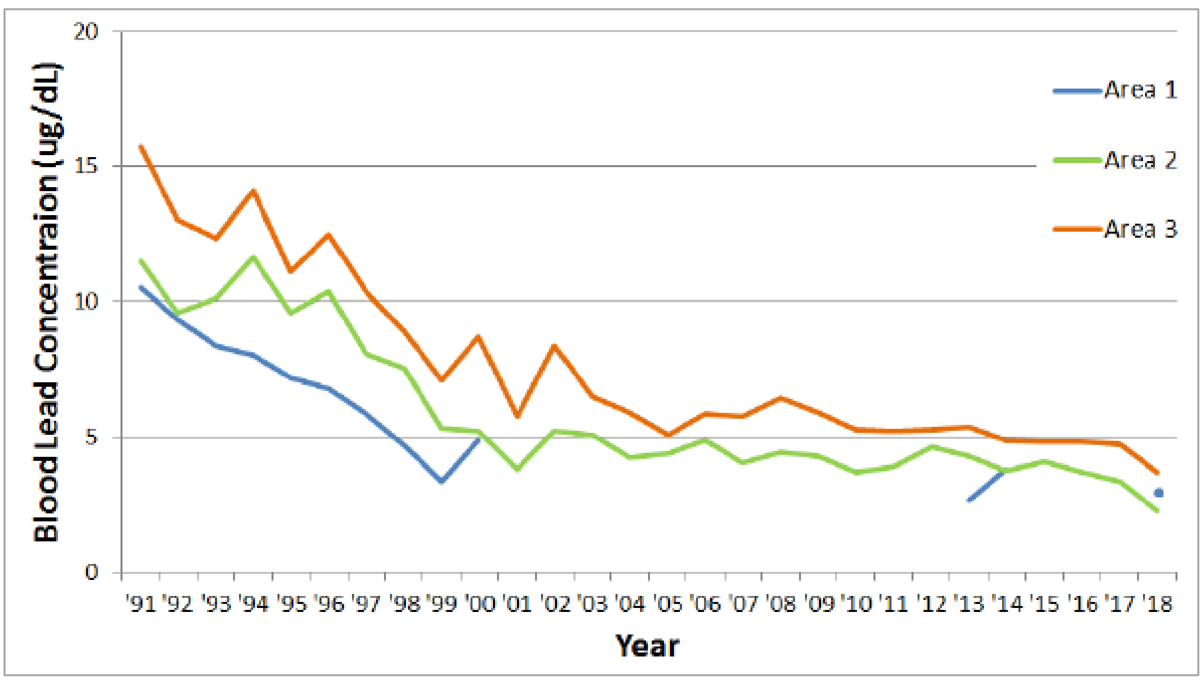


Figure 4-3 Trend of Blood Lead Levels (Geometric mean) in Children Ages 6-36 months in Trail and Rivervale (Areas 2 and 3, closer to smelter) and in Warfield, Oasis, Casino and Waneta (Area 1, further from smelter), 1991 to 2018 (Interior Health, 2019)

In 2019, the THEP announced an expansion to the soil testing and remediation program (that has been in place since 2007). Under this modified program, the focus will be on properties in areas selected in previous assessments (*i.e.*, those closest to the smelter operations), with priority given to properties where children under the age of 12 years have access. Based on the results of the testing, the THEP will then prioritize properties for further soil management actions, taking into consideration the age of children who may be present at the sites, the presence or absence of ground cover, and the measured lead concentrations. This program will be overseen by the British Columbia Ministry of Environment and Climate Change Strategy (BC Environment). Further work is in progress between Teck and BC Environment to develop a wide area remediation plan and a related public consultation process (THEP, 2019a)

4.2.5.3 Hamilton, Ontario

In 2008, Public Health Services in the City of Hamilton, Ontario initiated a study of lead exposure in children. Children (n=643) from North Hamilton under the age of 7 years were included in the study. Blood samples, parent interviews, and samples of drinking water, dust, and soil from the selected properties were collected. This particular area was selected as it was known to have been affected by historical and current industrial activities involving lead, it had older housing and infrastructure, and it included areas with known social and economic disadvantages relative to other areas in the City (City of Hamilton, 2011a,b).

The Hamilton study consisted of four (4) components:

- Community awareness campaign and study recruitment;
- Establishment of community clinics for blood lead testing;
- Questionnaires and household interviews; and,
- Collection and analysis of environmental data (drinking water, dust, and soil).

A ‘threshold’ level of 0.19 µmol/L (equivalent to approximately 3.9 µg/dL) was established. An algorithm was developed for follow-up with the parents of the affected child. These children were then contacted by a public health nurse to review results and to have the child re-tested for blood lead, as well as additional blood parameters (hematocrit and hemoglobin). Depending on the BLLs, the child was referred to a family doctor as needed. A home visit was completed by a public health inspector when required, and results were provided in letters with the child’s blood results and any other sampling results along with suggested actions to reduce environmental lead exposure (City of Hamilton, 2011b).

Less than 1% of the children included in the study presented BLLs above 10 µg/dL, and results for Hamilton were similar to other North American jurisdictions with available blood lead data. The geometric mean BLL for children in the Hamilton study was determined to be 2.2 µg/dL. No single exposure source of lead was identified. The recommendations to City Council included measures for free inspection and replacement of water service lines, the provision of on-tap water filters to low-income households, and the development of an environmental lead awareness program that targets high risk groups, including children, pregnant women and women of reproductive age (City of Hamilton, 2011a).

4.2.5.4 Montreal, Quebec

In 2005, it was determined that moderate concentrations of lead were present in the tap water of residences in the City of Montreal, Quebec. This resulted in the completion of a study by Levallois *et al*. (2013), who examined lead exposure *via* drinking water, indoor dust, and paint, and the relationship with BLLs in children living in four (4) areas of Montreal. The study was of cross-sectional design. Households with children between the ages of 1-5 years were randomly selected from the pre-determined boroughs of Montreal. At the time of blood sample collection by a pediatric nurse, an environmental technician completed a house inspection, collected samples of dust and tap water, and assessed the potential lead-content of interior walls using and x-ray fluorescence (XRF) analyser. From each residence, five one-litre samples of cold tap water were collected, with the first sample collected after a 5-minute flush, and the others after a 30-minute stagnation period. Floor dust samples were collected from three (3) different rooms: a child's room, another room frequently used by the child, and the entrance way to the home. In addition, samples of dust from windowsills were collected.

A statistically significant association was identified between elevated BLLs in children (defined as being greater than the 75th percentile of the BLL measured in the study – 1.78 µg/dL) and both indoor windowsill dust loading greater than 14.1 µg lead per square feet (adjusted Odds Ratio (OR): 3.2, 95%CI 1.3-7.8) and tap water lead concentrations greater than 3.3 µg/L (adjusted OR: 4.7, 95%CI 2.1-10.2). In general, non-Caucasian children presented higher BLLs than Caucasian children, with the means for both groups being determined to be 1.53 µg/dL and 1.27 µg/dL, respectively. Parental education levels also were associated with significant differences in BLLs between children, with children of parents who did not have a university diploma (mean 1.52 µg/dL) having higher BLL compared to children of parents with at least one parent having a university diploma (mean 1.3 µg/dL).

Ngueta *et al*. (2016) completed further analysis on the data for 298 children (ages 1-5 years) collected from Levallois *et al*. (2013), focused on lead in drinking water in the Montreal area. In this study of the data, Ngueta *et al*. (2016) used a cumulative water lead exposure index (CWLEI), which represented calculated values that took into consideration the lead concentrations in the households where each child resided, water consumption patterns, daily elimination rate, and other blood lead pharmacokinetics. A statistically significant ($p<0.0001$) association between CWLEI and BLL was identified. For each 1 unit increase in the CWLEI, regression analysis of the data suggested that the expected value of BLL should be multiplied by a factor of 1.10 (95%CI: 1.06-1.15); in other words, a 0.10 µg/dL increase in BLL would be expected (approximately 10%). A positive association between CWLEI and BLL was evident at dose levels of 0.7 µg lead per kg body weight (Ngueta *et al*., 2016). It was concluded that lead exposure from tapwater in Montreal, while within the Canadian drinking water guidelines, was a source of long-term lead exposure in children.

The publication of these studies resulted in a review by the City of Montreal, who concluded that the health risks were generally low and limited to young children (under the age of 6 years) and pregnant women who lived in homes built before 1970 that had less than eight (8) living units. Several mitigation measures that could be implemented at home that were recommended by the City of Montreal included:

- Incorporating the use of a pitcher water filtration system or a tap- filter that is certified for lead reduction;

- Use of bottled water (particularly for infants consuming formula that needs to be mixed with water);
- Allowing water to run for a few minutes after the water has turned cold, particularly if water has been standing in pipes for hours to days;
- Limiting water consumption to cold, not warm or hot water from the tap; and,
- Regular cleaning of screens and aerators to remove debris (City of Montreal, 2019).

4.2.5.5 St. John's, Newfoundland

The City of St. John's Newfoundland was identified by Bell *et al*. (2010) as having elevated lead concentrations in various environmental media in the absence of significant industrial point sources. The study of residential exposures to lead was triggered initially by the discovery of elevated lead concentrations in sediment layers collected from urban lakes in Newfoundland. Potential sources of lead were noted to include lead-based paint from existing and demolished structures, historical fire activity, the previous use of coal combustion for heating and transportation, and historical leaded-gasoline emissions.

A total of 1,231 soil samples were collected by Bell *et al*. (2010) from a total of 311 different residential properties during the years 2004-2005. Some housing in the areas was quite old, dating back to before 1926. The City was divided into 95 distinct neighbourhood areas, with at least three (3) homes from each neighbourhood included in the study. On each property, soil samples were collected within 5 m of a roadway, within 1 m of the house, and also from an open area of the property that was not adjacent to the house or roads. Samples of household dust were also collected from a sub-group of the residential properties from which soil samples were collected. In these residences, dust samples were collected from the most frequently used floor, the kitchen floor, and the windowsill of a frequently opened window.

Of the soil samples collected, 51% were identified as have concentrations of lead that exceeded the CCME residential guideline of 140 µg/g, with approximately 10% of all samples having lead concentrations above 1,000 µg/g. The majority of the samples with elevated concentrations were collected from the dripline of houses (maximum of 24,447 µg/g), along with open areas (ambient) further within residential yards (maximum of 12,738 µg/g). Roadside soil samples were typically lower, with a maximum concentration of 1,765 µg/g. On a spatial basis at the neighbourhood level, a clustering of high lead concentrations was evident in the downtown core. The 50th percentile for all soil samples combined was determined to be 148 µg/g, with the 50th percentiles for the ambient (open area), dripline, and roadway samples identified as 138 µg/g, 194 µg/g, and 136 µg/g, respectively.

Concentrations of lead in dust samples collected from windowsills were three-times higher than samples collected from entrance floors, and six-times higher than samples collected from kitchen floors. The highest dust loadings were identified from housing built before 1948, primarily in houses built before 1926. For housing built after the 1970s, there is no apparent decline in dust lead loadings despite the general trend towards less lead paint use during this time. Bell *et al*. (2010) suggested that this lack of decline may be due to renovations and remodelling activities.

Blood lead levels in St. John's were predicted by Campbell (2008) from the soil and dust data published in Bell *et al*. (2010) using the US EPA IEUBK model. For housing built before 1926, the predicted geometric mean BLL was estimated to be 6.5 µg/dL, with the geometric mean BLL declining in relation to property age down to 2.8 µg/dL or less. Similarly, the probability of exceeding the Canadian reference level at the time of 10 µg/dL was estimated based on age of housing, with 21.3% of children living in houses built before 1926 identified as likely to have BLLs above 10 µg/dL. A follow-up biomonitoring study determined that the geometric mean BLL in children (less than 7 years of age) living in St. John's was 1.12 µg/dL (Health Canada, 2013b). It is not evident what, if any, interventions were implemented in St. John's to reduce lead exposure beyond the provision of information on the City website (City of St. John's, 2019).

4.2.5.6 Butte, Montana

The City of Butte, Montana was an area of copper mining beginning in the 1870s, with the Anaconda Copper Mining Company (later acquired by Atlantic Richfield) creating a mine consolidation on Butte Hill. Nearby Walkerville became the highest silver producing mine camp internationally in 1890. The adjacent Silver Bow Creek was used as a conduit for mining, smelting and both industrial and municipal wastes, and large waste and mine tailings areas were present along the creek. The US EPA designated the Silver Bow Creek area as a Superfund Site in 1983. In 1987, this Superfund site area was expanded to include the communities of Butte and Walkerville, Montana, and the name of the site was changed to the Silver Bow Creek/Butte Area.

In 1990, an exposure study was completed in seven (7) different neighbourhoods within Butte. All seven (7) neighbourhoods were among the oldest in Butte. The geometric mean BLL in children ages 0-72 months (n=294 children) was 3.5 µg/dL, with a 95^{th} percentile BLL of 10.5 µg/dL and a maximum BLL of 25 µg/dL. In children and adolescents ages 72 months to 18 years (n=53), the geometric mean BLL was also 3.5 µg/dL, with a 95^{th} percentile BLL of 13.6 µg/dL, and a maximum of 18 µg/dL. The BLL in nursing and pregnant women (n=11 and 24 respectively) were lower, with geometric means of 2.4 and 2.1 µg/dL and maximums of 5.0 and 3.5 µg/dL. Potential exposure sources within each neighbourhood were noted, including age of housing, presence of lead paint and pipes, and the potential exposure to waste rock or mill tailings within the community. Several priority areas for clean-up were identified (Environ, 2014). In the 1990 exposure assessment, residence location (*i.e*., neighbourhood) and house age were found to be the strongest predictive factors of lead in paint, soil, and dust. Lead paint was significantly associated with lead contaminated soil, which was associated with lead household dust. Only lead in household dust was found to be associated with blood lead. Gardening and home-grown produce were not found to significantly contribute to BLL (Schoof *et al*., 2016). Following the 1990 exposure study, the University of Cincinnati recommended the development of a program to identify and address residential lead exposure from all sources, resulting in the creation of a multi-residential metals abatement program and the commencement of a free blood lead testing program for children. Any child with an elevated BLL (greater than 10 µg/dL in this study) was referred for a home evaluation including sampling and possible abatement and prevention education. The soil lead cleanup criterion applied in Butte was 1,200 µg/g, a value based on risk assessment and bioavailability studies (Schoof *et al*., 2016).

Clean-up activities were commenced between 1988 and 2004, focusing on mine-impacted lands and included removal and capping of sources of lead. It was noted that mining waste dumps and overburden piles were prevalent in the area and were known to be used as playgrounds by children. The Butte Citizen Technical Environmental Committee (CTEC) was formed in 1989 with funding from a technical assistance grant from the US EPA. A community planning process was commenced in 1990 to gather input from residents as to the goals of the clean-up efforts. In 1994, a Butte-Silver Bow Lead Intervention and Abatement Program was initiated (later renamed to Residential Metals Abatement Program in 2010). Between the 1990s and 2013, areas within the Superfund site boundaries for Silver Bow Creek/Butte were remediated into recreational areas (parks, playgrounds, athletic complexes, trails) and the construction of memorials and historic sites. Stormwater management improvements were also implemented during this time, as were ground water treatment and institutional controls to prevent the use of contaminated groundwater. Contaminated sediments were removed from areas in and around Silver Bow Creek (US EPA, 2014a).

A study by Schoof *et al*. (2016) and Environ (2014) evaluated BLL trends in children ages 1 to 5 years (n=2,796) between the years 2003 and 2010. Results were compared in relation to a population from a reference database from the NHANES program (n=2,937, age, sample date and body weight matched). The objective of the study was to evaluate the effectiveness of the source and exposure reduction efforts after a 25-year period of remediation.

Weighting factors were applied to the data for sex, age, season of blood test, house age, poverty level, and race as Butte to NHANES ratios based on the percentage of records in each dataset. A summary of the BLL results by sample year in Butte are presented in Table 4-5 (Environ, 2014). By the years 2009 and 2010, BLLs in the Butte area were no longer statistically significantly higher than the NHANES reference data (Environ, 2014), suggesting that the intervention programs were successful.

Table 4-5 Comparison of Measured BLLs in Children (Ages 1-5 Years) in Butte in Comparison with a Matched Reference Group from the National Health and Nutrition Evaluation Survey (NHANES) 2003 - 2010

Sample Year	Butte Group					NHANES reference, Geometric mean (µg/dL)
	N	Child BLL, Geometric Mean (µg/dL)	Child BLL, 95th Percentile (µg/dL)	Percent Children with BLL ≥ 5 µg/dL (%)	Percent Children with BLL ≥ 10 µg/dL (%)	
2003	351	3.49	9.10	33.6	3.4	2.05 (n=753)
2004	319	4.36	9.51	44.8	4.4	
2005	312	3.35	8.60	24.7	2.6	1.8 (n=806)
2006	326	2.63	7.03	16.0	1.8	
2007	342	2.44	7.90	16.1	2.0	1.72 (n=676)
2008	324	2.55	9.15	20.1	4.0	
2009	361	2.01	6.80	10.8	1.4	1.51 (n=702)
2010	461	1.55	6.60	9.5	1.5	

Shaded cells represent data significantly different from the Butte geometric means for the same time period, as identified by Schoof *et al*. (2016).

Significant differences in BLLs between neighbourhoods within Butte were also identified by Schoof *et al*. (2016). The Uptown region (which included the city center – an area located on top of former mine workings) and the Flats region (which included lower elevation areas located further from past and present mining areas, with newer housing) were considered separately. However, the differences in the rate of BLL decline over the 2003 to 2010 period were not statistically significant between the Uptown and Flats areas of Butte. As of 2010, 498 abatements have been completed (288 for soil and 210 for lead) in the Uptown neighbourhood, compared with only 47 abatements in the Flats neighbourhood (6 for soil, 41 for paint). Schoof *et al*. (2016) concluded that community-wide remediation measures rather than lead-interventions within homes and improved screening efforts contributed to the overall decline in BLLs over the 2003-2010 period. A proportion of children with BLLs greater than 5 µg/dL was identified in Uptown; however, in addition to proximity to mine waste, children in this area were more likely to reside in pre-1910 housing with a high proportion of property rentals (Schoof *et al*., 2016).

While the BLLs in Butte achieved parity with the NHANES reference group by 2009/2010, additional BLL screening was recommended, with improved detection limits and data collection practices. It was also recommended that additional community participation in the program be promoted, in addition to further education and outreach regarding exposure reduction programs (including lead-paint abatement) (Environ, 2014).

Some of the ‘lessons learned’ regarding the US EPA Superfund work in the Silver Bow Creek/Butte area were noted in a summary report by the US EPA (2014a), and included the following:

- Community-led development of land reuse plans were useful to the clean-up process. Community feedback resulted in historic preservation of the area’s mining activity and helped to identify other use priorities for former mine waste areas. These aspects helped encourage investment and provide social, economic, and ecological benefits.

- Local governments are key to engaging stakeholders for the purposes of discussing site reuse opportunities, to host various reuse projects, and to establish planning tools and resources.

- Successful redevelopment requires the protection of human health. The long-term clean-up plan incorporated a comprehensive testing and clean-up program for residential yards and attics. Governmental organisations and industrial proponents work together to ensure that residents are protected from any residual contamination within the reclaimed areas.

- Cooperation and Communication between stakeholders and the community, creativity and pragmatism are key to the alignment of reuse goals with clean-up plans. State and intergovernmental organisations are important to supporting cleanup and redevelopment.

- Partnerships with various organizations are important for achieving goals. The Silver Bow Creek/Butte project involved collaborations with Habitat for Humanity and the National Affordable Housing Network, and the Montana Economic Revitalization and Development Institute.

4.2.5.7 Herculaneum, Jefferson County, Missouri

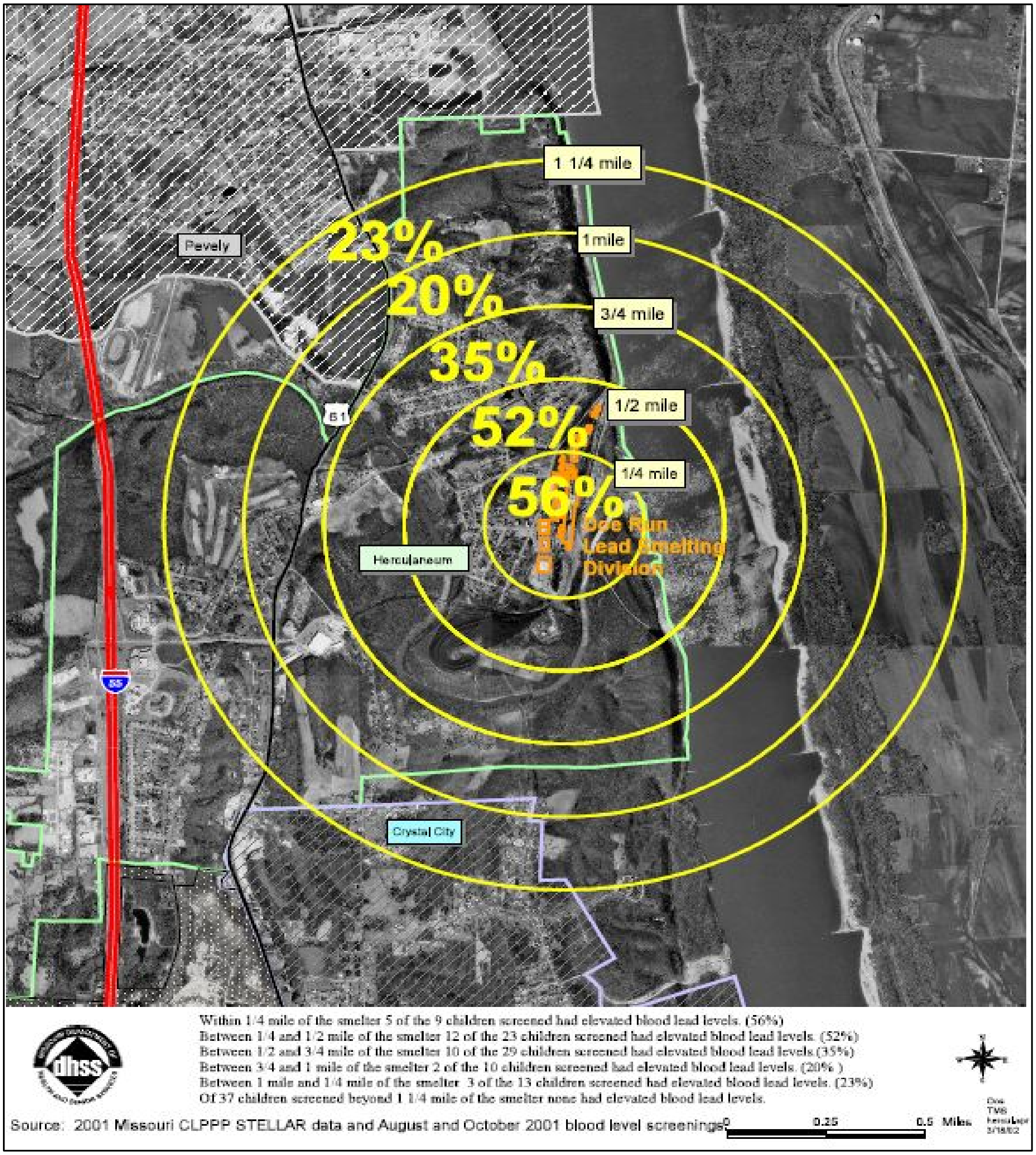
The Herculaneum lead smelter is located 40 km southwest of St. Louis, Missouri. The smelter operated for over 100 years and was owned and operated by the Doe Run Company. Operations ceased in 2013, and the site is being modified to provide infrastructure for transportation (rail, road, river) as the Riverview Commerce Park LLC Mississippi River Port (Doe Run Co., 2019).

The facility historically included a smelter plant, a 24-acre slag storage pile, and a sulphuric acid plant, encompassing approximately 52 acres of land. The facility processed lead ore which contained roughly 80% lead sulphide and was transported *via* truck from various mines and milling operations located southwest of Herculaneum. Residential areas have been built up around the smelting facility, with several homes within 200 feet of the smelter plant and slag piles (ATSDR, 2002a,b).

The elementary and high schools within Herculaneum at the time were located about 0.5 miles (approximately 800 m) north of the smelter. The middle school was located about one mile (1.6 km) north-northwest of the smelter, and the primary school (grades kindergarten to 3) was located about 2 miles (3.2 km) to the northwest (ATSDR, 2002a).

A complaint concerning the spillage of lead concentrate on the streets of Herculaneum was made in August of 2001. The Missouri Department of Natural Resources (MDNR) investigated and confirmed that lead concentrate was being spilled along the haul routes within the Town of Herculaneum. An exposure investigation conducted by ATSDR in 2001 indicated that lead in paint and water did not appear to be significant contributors of lead exposure among children living in these homes (ATSDR, 2002a). The Missouri Department of Health and Senior Services (DHSS) also released the results of a blood lead sampling program conducted in 2001 involving 935 people. Using these data, the DHSS characterized the prevalence of elevated BLLs (using the reference level valid at the time – 10 µg/dL or above) among children (6 years of age and younger) with proximity to the smelter. A map of this study is provided as Figure 4-4. Of the 935 people tested, 118 were children under the age of 6 years. Of these young children, a total of 33 out of 118 (or 28%) had a BLL ≥ 10 µg/dL. For those children living closest to the smelter, 30 of 67 (or 45%) of children tested (under the age of 6 years) had a BLL ≥ 10 µg/dL (ATSDR, 2002c). The average BLL for all children (under the age of 6 years) tested in Herculaneum during 2001 was 8.0 µg/dL (range 2 – 31 µg/dL), significantly greater than the national average of 2.0 µg/dL at the time, as cited by ATSDR (2002c).

Sampling and analysis of soil, air, interior dust, and street dust confirmed that significant lead contamination was present throughout the community, with concentrations of lead in yard soil and street dust reaching maximum levels of 33,100 µg/g and 300,000 µg/g, respectively (ATSDR, 2002a).



[3]**Figure 4-4 Herculaneum Missouri – Elevated Blood Levels (BLL ≥ 10 µg/dL) in Children Under 6 Years of Age in 2001**

[3] Source: Missouri Department of Natural Resources. Available at: http://www.dnr.mo.gov/env/herc/index.html

The Doe Run Company was instructed by various governmental authorities to expedite on-going clean-up efforts and to reduce or eliminate future contamination of the town. In consultation with stakeholders, the Doe Run Company took additional intervention measures (beyond those stipulated in an earlier Abatement and Cease and Desist Order), including:

- Reduction of emissions (both smelter and fugitives) through the installation of equipment up-grades and process changes to meet National Ambient Air Quality Standards (NAAQS) for lead emissions of 1.5 µg per dry standard cubic meter;
- The removal and replacement of soil from public and private property including parks, school grounds, backyards, and along roadsides where lead concentrations exceeded 400 µg/g with first priority given to those yards where children under 6 years old resided;
- The removal and cleaning of in-house dust as per US EPA-developed protocols in residential homes along the haul route;
- HEPA filter vacuum offered to all residents to assist in controlling interior dust levels;
- Further modifications to the methods used by the Doe Run Company when handling and transporting lead ore concentrate in an effort to eliminate spillage during transport; and,
- Voluntary property acquisition of residential properties within approximately 600 m of the smelter where children (younger than 6 years of age) were residing (*i.e.*, high-risk families).

In addition to the intervention measures above, a health education program for residents and physicians was initiated to increase the general awareness regarding public health issues surrounding lead. In September of 2002, a voluntary community-wide venous blood lead testing program was offered to the residents of Herculaneum. This testing was intended to serve as a follow-up to the 2001 blood lead program. In total, 340 people participated, 58 of which were children under the age of 6 years. The mean BLL of children (under the age of 6 years) tested in 2002 was 6.4 µg/dL (range 2 to 28 µg/dL) with 14% (8 of 58) having a BLL ≥ 10 µg/dL. This represented a 50% reduction in the prevalence of children with a BLL≥ 10 µg/dL compared to 2001 (ATSDR, 2003). For those children under the age of 6 years living in close proximity to the smelter (*i.e.*, living east of Highway 61/Commercial Blvd.; approximately ¾ of a mile from the smelter), the results of the 2002 testing indicated that 17% (8 of 46) of children had a BLL ≥ 10 µg/dL. This represented a 62% reduction in the prevalence of children living in close proximity to the smelter with a BLL ≥ 10 µg/dL compared to the 2001 dataset (ATSDR, 2003). A summary of blood lead data collected for young children (under the age of 6 years) within Herculaneum is presented in Table 4-6.

Table 4-6 Summary of Blood Lead Levels for Children (Less than 6 Years of Age), Herculaneum, Missouri, 2001 and 2002 (ATSDR, 2003)		
Parameter	**2001**	**2002**
Total number of children tested	118	58
Range of BLLs for children tested	ND - 31µg/dL	2 µg/dL – 28 µg/dL
Mean BLL of children tested	8.0 µg/dL	6.4 µg/dL
Number of children with BLLs ≥10 µg/dL	33 of 118 (28%)	8 of 58 (14%)
Number of children living in close proximity of the smelter who were tested[a]	67	46
Number of children living in close proximity of the smelter with BLLs ≥10 µg/dL	30 of 67(45%)	8 of 46 (17%)

[a] Close proximity refers to individuals living east of Highway 61/Commercial Blvd.

By November 2005, a total of 407 residential yards with soil lead concentrations above 400 µg/g in Herculaneum had been remediated, and Doe Run purchased the majority of residential properties within 3/8 mile (approximately 600 m) of the smelter (City of Herculaneum, 2006).

Several intervention strategies that ranged from the reduction of smelter emissions to the roll out of an educational program were employed between 2001 and 2002 and were successful in reducing BLL among children. However, BLLs still remained ≥ 10 µg/dL for 14% of children under 6 years of age, with many of those children living in close proximity to the smelter. However, the re-location of high-risk families living in close proximity to the smelter was likely a significant contributor to the reduction in BLLs between 2001 and 2002 observed in the cohort living east of Highway 61/Commercial Blvd (ATSDR, 2003).

More recent blood lead or monitoring data could not be identified in 2019 for Herculaneum to evaluate the effect of the facility closure on lead exposures or long-term trends in BLLs.

4.2.5.8 Broken Hill, Australia

Lead has been mined in Broken Hill, New South Wales, Australia for more than a century. In response to increasing public concern over mining activities and increased awareness of the effects of higher BLLs, a blood lead survey of the city's children was conducted in 1991. The results of the survey indicated that nearly 25% of the children included in the study had BLLs greater than the National Health and Medical Research Council level of concern at the time (25 µg/dL), and approximately 86% of children had BLLs greater than 10 µg/dL (Lyle *et al*., 2001; Boreland *et al*., 2008, 2009). By 1994, a government funded program was formally initiated in an effort to reduce BLLs among pre-school children (Lyle *et al*., 2001).

The program aimed to reduce BLLs among the young children of Broken Hill to levels observed in non-contaminated areas throughout Australia (Lyle *et al*., 2001). The program included five (5) components:

1. Blood lead monitoring targeting all pre-school aged children;
2. Case management of children with high BLLs (including home remediation services);
3. Public education and health promotion;
4. Remediation of public land; and,
5. Evaluation, research, and development.

Uncovered mine tailings dumps were capped at the end of the 1990s to reduce lead exposure *via* soil and dust (Dong *et al*., 2019). In addition, the use of leaded gasoline was eliminated entirely by 2002 within Australia (Dong *et al*., 2019).

The overall geometric mean BLL among children (ages 1 to 4 years) in Broken Hill dropped from 16.3 µg/dL to 5.8 µg/dL (representing a 64% decline) between 1991 and 2007, following the implementation of the government-funded program. In the highest risk zone (*i.e*., areas closest to the mines), the geometric mean BLL dropped by 70% (from 27.3 µg/dL in 1991 to 8.3 µg/dL by 2007). Boreland *et al*. (2008) indicated that children closest to the mine site were likely to benefit most (*i.e*., see the greatest reductions in BLLs) as a result of extensive remediation of contaminated lands adjacent to the mine site. Dust fall measurements (in high, medium-high, medium and medium-low risk areas) before and after remediation efforts were presented to support this hypothesis.

Due to the nature of the multi-layered approach used in Broken Hill (*e.g.,* a combination of large scale remediation, individual home remediation, health promotion, *etc*.), it was not possible to attribute the impact of any single intervention with respect to the efficiency in reducing BLLs (Boreland *et al*., 2008). However, according to the literature cited by Boreland *et al*. (2008), zonal remediation within communities with wide-spread contamination was likely more effective at reducing BLLs than other interventions. Boreland *et al*. (2008) suspected that the most likely explanation for the reduction in BLLs among children living within the high-risk zone of Broken Hill was the extensive remediation of contaminated lands on and adjacent to the mine site, rather than the other approaches.

To help clarify this hypothesis, Boreland *et al*. (2009) examined, through the use of a randomized control trial (RCT), whether or not the remediation of individual homes would lower BLLs among young children living in Broken Hill. Boreland *et al*. (2009) also examined whether or not childhood BLLs were correlated with changes in indoor lead loading following the completion of lead remediation work. Home lead remediation was included in the case management for those children who had BLLs >15 µg/dL (children with BLLs > 30 µg/dL were offered immediate home remediation). In addition, a subset of eligible children with BLLs between 15 and 29 µg/dL participated in the RCT, where 10 intervention activities involving internal improvements (*e.g.,* ceiling dust removal, sealing of ceiling and cornices, removal of contaminated soil, replacement of floor coverings, replacing windows, cleaning floor coverings, etc.) were applied. The overall intent was to provide each home with the same level of ‘lead safety’ (Boreland *et al*., 2009). A total of 88 children (or 44 pairs) participated in the RCT (each pair including a child with elevated BLL and another without). The BLLs were measured in both children receiving home remediation services and their paired control partner before and approximately 6 months after remediation was complete. The study concluded that home remediation did not have a significant effect on reducing BLLs. Further, no evidence of a dose-response relationship was apparent between BLL and indoor dust levels 10 months after the home remediation activities were completed (Boreland *et al*., 2009).

Blood lead in children continues to be evaluated in Broken Hill, with annual reports provided online. All children of 5 years of age or less are offered blood lead testing. Since the initial lead study in 1991, the geometric mean BLL in Broken Hill has decreased from 16.7 µg/dL to 5.7 µg/dL in 2017 (Table 4-7). As of 2011, finger-prick testing has been offered to parents, and various recruitment and communication strategies have been employed to improve participation. Blood lead monitoring data for the years 2014 to 2017 reveal that BLLs in Aboriginal children are significantly higher than for non-Aboriginal children (Table 4-7). Less Aboriginal children seem to participate in the testing program, however this number is increasing over time, and as a result, the West New South Wales Ministry of Health notes that the geometric mean BLL for Aboriginal children has increased in the more recent data (2017 vs. 2014) due to improved participation and a more realistic reflection of BLLs within that population.

Dong *et al*. (2019) completed an analysis of children's BLLs (ages 1-5 years) in the Broken Hill area, taking into consideration household soil lead, urban dust concentrations, sociodemographic factors, lead ore production, and the influence of weather conditions including wind direction and patterns. One of the objectives of the Dong *et al*. (2019) study was to identify if historical or contemporary mine emissions were influencing lead exposure in the area. One mining company in Broken Hill was still operating during the 2011 to 2015 study period. A total of 4,852 children (ages newborn to 5 years) were included in the study, with 24% of this group identifying as Aboriginal and 76% as non-Aboriginal. The overall geometric mean BLL for the study population as a whole was 4.3 µg/dL, with the Aboriginal geometric mean being higher (7.03 µg/dL) compared to that of the non-Aboriginal group (3.70 µg/dL).

Regardless of Aboriginal status, increasing distance from the mining operation was found to be associated with decreased BLL, with the geometric mean BLL decreasing from 5.25 µg/dL at distances less than 2 km from the mine, to 4.49 µg/dL between 2 to 4 km from the mine, to 3.89 µg/dL at distances more than 4 km from the mine. Children who lived downwind of the mine and within less than 250 m were observed to have significantly (75%) higher BLL than children located upwind at a similar distance from the mine. This difference was apparent even after adjustment for lead-paint exposure risk from older housing. However, due to a large dust storm in 2009, the spatial distribution of soil lead concentrations had been disrupted and re-distributed. Despite this readjustment in soil concentrations, increased BLLs in closer proximity to the mine remained, suggesting that contemporary mine emissions influence child lead exposures in the area. A 1% increase in soil lead concentration was found to be associated with a 0.13% in child BLL. A relationship between historical BLL and data regarding lead production at the mine between 1991 and 2013 indicated that annual BLLs were significantly associated with lead ore production ($p<0.01$) (Dong *et al*. 2019).

Table 4-7	Age- and Sex-Standardized Blood Lead Levels, Children Ages 1 to 5 years, Broken Hill Australia			
Year	**Number of Children**	**Geometric Mean (µg/dL)**	**Proportion with BLL > 5 µg/dL**	**Reference**
2017	All Children (n=730) Aboriginal (n=221) Non-Aboriginal (n=509)	5.7 (All) 8.7 (Aboriginal) 4.6 (Non-Aboriginal)	- 78% 42%	WNSW HIU, 2018
2016	All Children (n=687) Aboriginal (n=207) Non-Aboriginal (n=480)	5.9 (All) 7.6 (Aboriginal) 5.2 (non-Aboriginal)	- 78% 50%	
2015	All children (n=679) Aboriginal (n=178) Non-Aboriginal (n=501)	5.8 (All) 9.3 (Aboriginal) No data for non-Aboriginal	47% 79% 35%	NSW MOH, 2016
2014	All children (n=719) Aboriginal (n=183) Non-Aboriginal (n=536)	5.2 (All) 7.5 (Aboriginal) No data for non-Aboriginal	- 63% 24%	NSW MOH, 2015
2011 – 2015	All children (n=4852) Aboriginal (n=1158) Non-Aboriginal (n=3694)	4.31 (All) 7.03 (Aboriginal) 3.7 (Non-Aboriginal)	42.56 70.21 33.89	Dong et al., 2019

In 2016, the Broken Hill Environmental Lead Study (BHELS) was commissioned by the New South Wales Environmental Protection Authority to help inform on-going remediation efforts. It is intended to be a 4-year study. The objectives of BHELS are to:

1. Identify likely source areas and emission sources of lead contributing to airborne lead concentrations within Broken Hill; and,
2. To monitor airborne and deposited lead levels for a 2-year period to evaluate the efficacy of remediation.

The findings of this study are not available (NSW EPA, 2019).

4.2.5.9 Point Pirie, Australia

Port Pirie is a community of 15,000 people and is situated on the Spencer Gulf, approximately 250 km north of Adelaide in the state of South Australia. The area is home to one of the largest lead-zinc smelters in the world and is operated by an international metals business (Maynard *et al*., 2003; Nyrstar, 2018). Lead emissions from the smelter have occurred for over 150 years, resulting in contamination to the surrounding environment with various metals, including lead, zinc, arsenic, and cadmium (Maynard *et al*., 2003; Taylor, 2012).

In 1984, the South Australian Government implemented a 10-year program with the objective of remediating Port Pirie and reducing the BLLs among children to below the existing National Health and Medical Research Council (NHMRC) 'level of concern' at the time (30 µg/dL). The program focused on lead exposures related to historical contamination of the city and houses given that smelter emissions were thought to be at sufficiently low levels (Maynard *et al*., 2003). The initial focus of the program was on the identification of children with BLLs above the 'level of concern' and decontaminating their homes to reduce metal exposures, followed by a systematic remediation of the most heavily impacted residential areas. Approximately 2,200 houses with children with elevated BLLs were remediated as part of the 10-year program, with activities including the removal of dust and paint, repairs to reduce dust entry, and soil replacement being completed. Over the 10-year period, BLLs were significantly reduced from 30% of children with BLLs >25 µg/dL in 1984 to approximately 6% of children by 1993 at a cost of 25 million $AUD (Maynard *et al*., 2003). A review of the program highlighted a number of challenges in further reducing children's BLLs to the revised NHMRC 'level of concern' of 10 µg/dL. The review also highlighted issues concerning the on-going contamination and/or recontamination of houses as a result of ongoing smelter emissions and the need to reconsider the performance of smelter emissions and indoor exposures of young children (Maynard *et al*., 2003).

A second lead assessment program commenced in 1994 and included resources to identify major sources of lead and strategies to reduce lead exposures within the home. Maynard *et al*. (2003) indicated that, since the start of the second Lead Program, the proportion of children with BLL ≥ 25 µg/dL was reduced, however 61% of children still had BLLs greater than the national goal of 10 µg/dL at the time. The second Lead Program was multifaceted, in that several different interventions were employed, including:

- The development of buffer zones and relocation of families from the most impacted areas;
- House decontamination (*i.e.,* removal of dust and paint, repairs to reduce dust entry, and soil replacement); however, due to recontamination issues, this intervention was limited to those with children with BLLs greater than 20 µg/dL;
- Family education and in-home support;
- Education programs to emphasize the need to avoid the use of 'tank rainwater' due to atmospheric contamination;
- Dust control measures implemented by the smelter facility to control dust and dust re-entrainment from stockpiles and roads (*e.g*., construction of earth berms with dense vegetation);
- Smelter emission controls – confinement of stockpiles, water spraying of surface dusts, improved exhaust emissions of processing plants, *etc*.;
- The implementation of measures to stop workers from leaving the site in contaminated clothing or without showering. Although earlier studies found an association between having a parent who works at the smelter and elevated BLLs among children, Maynard *et al*. (2003) indicated that more recent data no longer supported this association in young children; and,
- The implementation of different soil abatement interventions depending on the concentration of lead in residential soils. At the extreme, complete soil replacement was triggered when lead in soil exceeded 10,000 µg/g, and 50 mm of clean soil was applied when lead levels were between 2,500 and 10,000 µg/g.

It was recognized that family support programs did not appear to reduce BLLs among those children with elevated BLLs that were followed using serial blood lead testing. It was also recognized that it was not possible to differentiate the effects of different interventions from the typical decline in BLLs observed with age among pre-school children over time due to changes in exposure patterns. Although earlier studies indicated that soil lead levels were significantly related to BLLs, Calder *et al*. (1990) concluded that household soil lead levels only accounted for 5 to 10% of the variation in BLLs among children. Despite various intervention efforts, ongoing smelter emissions were considered to be the dominant source of lead in household dust. More specifically, the production area including the sinter plant and blast furnace was identified as key emission sources of fine particulate containing lead (Maynard *et al*., 2003).

In 2000, a Lead Program entitled "Ten by 10" was implemented with the goal to have 95% of all Port Pirie children below a BLL of 10 µg/dL by 2010. The 2011 blood lead monitoring data indicated that 25.5% of all Port Pirie children tested under the age of 5 years (excluding the use of surrogate values[4]) had BLLs greater than 10 µg/dL (SA Health, 2011; Taylor, 2012). The first half of the 2012 blood lead monitoring data indicated that that 27.6% of Port Pirie children tested under the age of 5 years (excluding the use of surrogate values) had BLLs greater than 10 µg/dL (SA Health, 2011). A study by Taylor (2012) indicated the primary reasons for not achieving the goal were that clean-up of household dust and soil was incomplete and, of most importance, the primary source of lead exposure (*i.e*., smelter emissions) was not eliminated and was on-going. As a result, the community continues to be impacted by atmospheric emissions.

A study by Simon *et al*. (2006) followed thirteen (13) Port Pirie infants (from birth to approximately 36 months of age) and their mothers on a monthly basis. Blood from both infants and mothers was collected in addition to hand-wipe samples from both infants and parents. The central focus of the work by Simon *et al*. (2006) was to determine the age at which BLLs among infants begin to rise after birth and to characterize the shape of the BLL curve during the first 18 months of life. As part of the study, the importance of different exposure pathways (as they relate to the contribution to BLLs and hand loading) was also investigated, in particular, the role of hand-to-mouth contact.

Simon *et al*. (2006) identified predictive factors for elevated BLL among infants in Port Pirie: age of infant, hand-lead loading of both the mother and infant, and the location of the residence relative to the smelter. The data indicated that mothers with elevated pre-natal BLLs typically had infants that also developed elevated BLLs. As a result, Simon *et al*. (2006) emphasized the importance of early blood lead monitoring, even prior to birth, to assist in developing improved strategies to reduce lead exposure.

The proximity to the smelter was shown as a major determinant of lead exposure in Port Pirie with house type (new construction versus older less well-constructed sites) having a potential influence on this relationship. Simon *et al*. (2006) indicated that relocation of infants from high risk areas on a case-by-case basis was an important and effective intervention strategy, however, excessively expensive to be implemented on a population basis. A number of potential confounding variables were investigated (*i.e*., season of birth, occupation, smoking, keeping a pet, bed type, location within house of sleeping, and technique used to dry clothes). None of these factors were found to be associated with either hand-lead or BLLs. Simon *et al*. (2006) concluded that the intervention strategy required in Port Pirie would consist of reduction smelter emissions followed by a thorough household remedial program. Simon *et al*. (2006) highlighted the need for further research concerning the identification of large deposits (or reservoirs) of dust in homes and methods needed to both remove and prevent ongoing recontamination.

[4] A surrogate value represents a child's predicted BLL at birth, estimated using the mother's blood lead level.

The Targeted Lead Abatement Program (TLAP) was developed in 2014 to identify current and potential lead exposure reduction strategies, and to assess which strategies have the greatest impact on reducing childhood BLL. As part of this Strategy, the Nyrstar Port Pirie Redevelopment Project transformed the smelter into a multi-metals processing and recovery facility, with an aim of reducing emissions (TLAP, 2018). The current target is to attain BLLs of less than 5 µg/dL for all children under 5 years of age. The TLAP program includes a comprehensive website for public use, describing the various exposure reduction strategies, that include phytoremediation, renovation fact sheets, nutritional guidance, indoor exposure reduction information, gardening fact sheets, and a mobile educational centre that promotes information about the centre (TLAP, 2018).

Available biomonitoring data from the years 2009 to 2018 in Port Pirie suggest that in general, the BLL of children less than 5 years of age have gradually decreased (Figure 4-5), with the geometric mean in 2018 being 4.6 µg/dL (SA Health, 2019a). In 2018, 49.5% of the children (n=592) tested that year had BLLs of less than 5 µg/dL, and 75.7% had BLLs less than 10 µg/dL (SA Health, 2019a). The geometric mean of very young children (less than 2 years or 24 months of age), however, continues to be above the Australian NHMRC target level of 5 µg/dL (SA Health, 2019a).

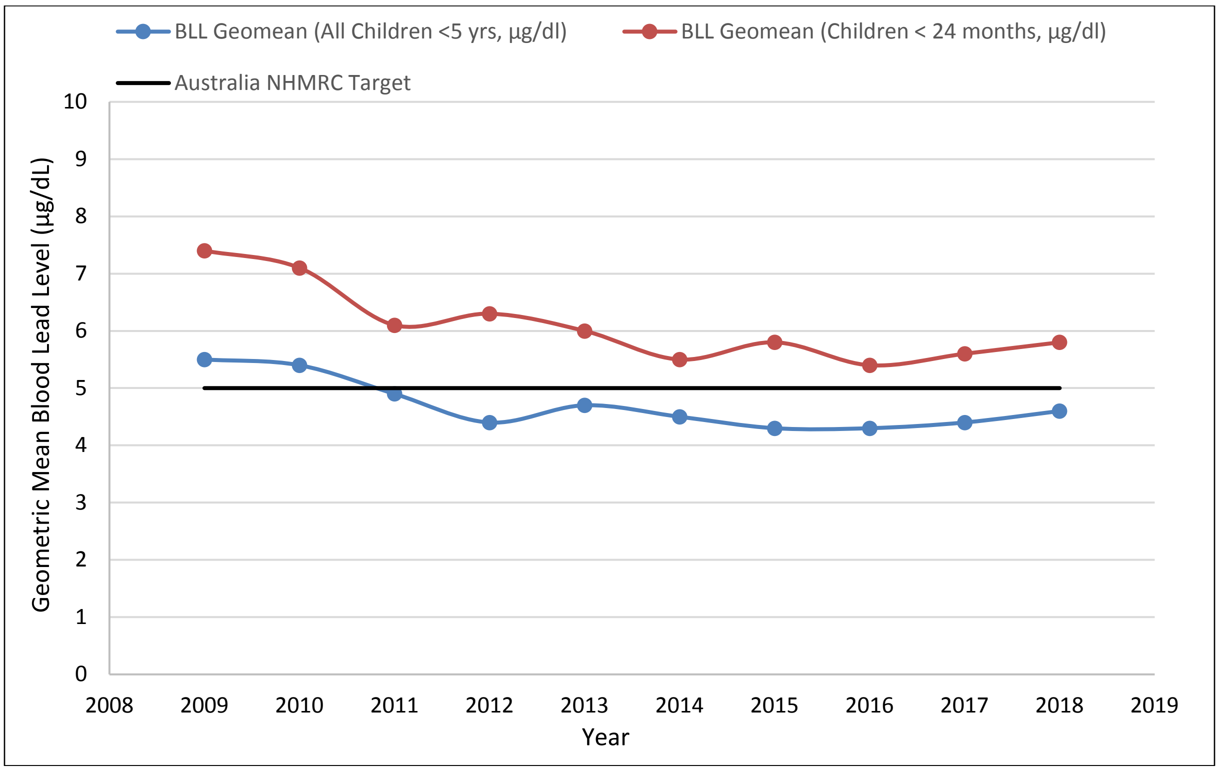


Figure 4-5 Blood Lead Monitoring in Children, Port Pirie, Australia (SA Health, 2019a)

In summary, at Port Pirie, Australia, the BLLs in children have been reduced over time as a result of multiple intervention strategies that have taken place for more than 30 years. However, the key objective has not yet been achieved – to have all children with a BLL below 5 µg/dL. A recent news release from South Australia Health indicates that the Nyrstar facility is currently operating within the required air quality guidelines, but on-going efforts are being made to further reduce emissions and manage dusts in the area. The TLAP program has been modified to include daily cleaning of high-use community facilities, replacing old bark chips at playgrounds, mulching of exposed soils and seeds, and improved cleaning in high-risk areas. The news release also notes that the modifications planned for the smelter are anticipated to be fully implemented by the end of 2019 (SA Health, 2019b).

4.2.6 Findings Regarding Population-Level Lead Interventions in the Primary Literature

The following discussion provides an overview of published literature describing the effectiveness of various interventions used to mitigate lead exposure. Systematic reviews presenting analyses of data from multiple studies are summarized in Section 4.2.6.1, and reviews of primary studies evaluating interventions in Section 4.2.6.2.

4.2.6.1 Systematic Reviews of Educational and Household Interventions

A systematic search and review of the primary scientific literature was completed by Yeoh *et al*. (2012). Randomized controlled trials (RCTs) or '*quasi-randomized*' control trials where participants were assigned to either an intervention or control group and where at least one standardized outcome measure was reported were selected for potential inclusion. Educational interventions were classified as activities that address parental awareness of exposure pathways, domestic dust control measures, and hygiene practices. Household environmental interventions included activities such as soil abatement, painting, specialized cleaning, repairs, maintenance, and temporary lead hazard containment measures. A combination of these two (2) broad types of interventions was also considered. Three (3) basic outcome measures were considered by Yeoh *et al*. (2012), including:

- Blood lead levels in children;
- Cognitive and neurobehavioural outcomes; and,
- Measurements of household dust levels.

A total of thirteen (13) RCTs, and one quasi-randomized control trial study, were selected for inclusion by Yeoh *et al*. (2012), representing 2,656 children less than 6 years of age. The fourteen (14) studies were placed into sub-categories depending on the type of intervention (education, environmental or a combination of the two):

- Educational programs;
- Environmental:
    - Dust Control Measures; and
    - Soil Abatement;
- Combination (education and dust control or soil abatement).

The results of the meta-analysis performed on these data indicated that educational interventions were not effective in reducing BLLs. It was noted that a non-statistically significant trend was observed concerning the effectiveness of educational interventions in preventing the number of children exceeding a BLL of 15 µg/dL; however, further data including children with moderate BLLs are needed to clarify this potential benefit. The meta-analysis conducted on data from the dust control subgroup also indicated no evidence of effectiveness (Yeoh *et al*. 2012). Due to significant differences in design among studies that examined soil abatement (removal and replacement) and a combination of interventions (education and dust control), a metal-analysis could not be conducted on these data. Yeoh *et al*. (2012) concluded that, based on the current data, there was insufficient data to draw any conclusions concerning the effectiveness of soil abatement techniques or a combination of interventions (*i.e.,* education and dust control measures). Yeoh *et al*. (2012) acknowledged that these results may appear to contradict much of the observational data that report declines in dust lead loadings and average BLLs; but posed the question as to whether or not the intervention applied (*e.g*., lead hazard controls or partial abatement) led to a significant reduction (or increase) in BLL among very young children who exhibit mouthing behaviours.

A systematic review of RCT, or quasi-RCTs, by Nussbaumer-Streit *et al*. (2016) evaluated the effectiveness of household educational or environmental, or combinations of education and environmental interventions, to prevent lead exposure in children under 18 years of age. This review was intended to be an update of the findings of Yeoh *et al*. (2012) and included more recently published data and the exclusion of others that did not meet the modified selection criteria. Nussbaumer-Streit *et al*. (2016) reviewed a total of fourteen (14) studies that involved a combined total of 2,643 children, with most studies being conducted in urban North American areas. The duration that the various interventions were applied ranged between 3 and 24 months. This review also concluded that based on the populations studied, no significant effect on reducing BLLs in children was evident in association with household educational interventions, and limited to no difference in BLLs was evident in relation to dust control interventions. The authors stated that US standards for lead household dust are outdated (note: these standards were updated in 2019, after the publication of Nussbaumer-Streit *et al*., 2016), and that the implementation of these standards during renovation or remediation work may actually contribute to childhood lead exposure by increasing lead dust levels within the home, particularly if proper precautions are not implemented. Nussbaumer-Streit *et al*. (2016) also noted that the evidence is insufficient to make conclusions regarding the effectiveness of soil abatement or programs involving both education and environmental intervention. However, the review concluded that additional trials are necessary to identify the most effective interventions for the reduction of childhood lead exposure.

A systematic review of RCTs that included low cost (<$2,500) in-home lead interventions was completed by Haynes *et al*. (2002). A total of five (5) articles were included in the analysis and included various interventions: education (3 studies); provision of cleaning supplies or equipment (2 studies); professional cleaning services (2 studies), and minor house repairs (1 study). The interventions took place over a period ranging from 6 to 48 months. Haynes *et al*. (2002) found no significant decline in mean BLLs among children from homes that had undergone low-cost in-home interventions compared to those that had not had any interventions completed. No significant difference between the intervention and control groups with respect to the proportion of children with BLLs greater or equal to 10 µg/L was identified. The low-cost interventions were, however, found to be effective in significantly lowering the proportion of children with BLLs greater than 15 µg/dL and 20 µg/dL (*i.e.,* a reduction of ≥ 50%). According to Haynes *et al*. (2002), these results are consistent with previous work suggesting lead intervention efforts have a greater impact on children with highly elevated BLLs. It was hypothesized that the limited effectiveness of dust interventions on lowering BLLs was due to the fact that the source of on-going dust contamination was not eliminated through the methods used. Haynes *et al*. (2002) concluded that, unless the ultimate source of house dust contamination is controlled, household dust intervention efforts will provide little efficacy in reducing BLLs.

4.2.6.2 A Review of Studies Concerning the Effectiveness of Educational and Household Interventions

When used alone, educational programs providing information concerning lead hazards and in-home dust mitigation techniques (*e.g.,* wet mopping, reducing soil track in, vacuuming, *etc.*) have been found to have limited effectiveness in lower BLLs among children (Taylor *et al*., 2011). Kegler and Malcoe (2004) tested the efficacy of community education (delivered by way of a lay health advisor) as the primary intervention in reducing mean BLLs among Native American children living in a former mining area and were unable to exclusively attribute the educational intervention efforts to declines in BLLs. Dugbatey *et al*. (2005) attempted to determine whether or not personalized educational interventions given to disadvantaged inner city pregnant women would reduce the probability of infants having a BLL ≥10 µg/L. None of the interventions employed (*i.e.,* hands-on instruction on cleaning techniques, property maintenance, hygiene and nutritional advice) reduced the probability of an infant having a BLL ≥10 µg/L.

A study completed by Lanphear *et al*. (2000) observed no significant change in BLLs among children whose families received information on lead poisoning prevention and cleaning techniques, and equipment and supplies to reduce lead-impacted house dust. Lanphear *et al*. (2000) observed that dust mitigation efforts did not appear to be effective in reducing BLLs unless conducted by professional dust mitigation teams. Similarly, Campbell *et al*. (2003) concluded that a one-time professional cleaning of homes occupied by children with elevated BLLs was effective in significantly reducing dust lead levels; however, dust lead levels returned to pre-cleaning levels within 3 to 6 months. Children in the exposure group with a geometric mean BLL of 14.5 µg/dL did not respond to the one-time cleaning session. Ettinger *et al*. (2002) also found significant reductions in most dust samples after a single professional cleaning; however, not all dust samples fell below federal standards for lead in residential dust, indicating that more intensive cleaning and lead reduction intervention strategies were required in order to achieve lead dust levels below federal residential dust standards. Continued in-home cleaning interventions completed once every two weeks by trained workers for one year resulted, on average, in a 17% decrease in BLLs among children (with an average age of 20 months) compared to pre-intervention levels (where the average measurement was 20 µg/dL). Rhoads *et al*. (1999) also observed that children in homes that were cleaned 20 or more times throughout the one-year period (*i.e*., those household that missed few cleaning appointments) had an approximately 34% decline in BLL. However, Rhoads *et al*. (1999) did not investigate house dust lead levels and BLLs after the intervention program was terminated to determine whether dust lead or BLLs increased after the program ended.

Shao *et al*. (2017) evaluated the effectiveness of the implementation of lead hazard control treatment using historical surveillance data (1992 to 2011) for BLLs in children living in Syracuse, New York. Interrupted time series analysis before and after the exposure intervention, and piecewise regression were completed to evaluate the changes and trends in BLL before and after interventions. A segmented time series method was used to evaluate potential seasonal variations in BLL. The interventions considered included the three (3) stages of lead prevention activities employed in Syracuse over a 20-year period:

- Stage 1: The 1993 implementation of State regulations for reporting child BLLs, lead screening and follow up, and the environmental assessment and abatement regulation implementation in 1995. Both sets of regulations are still in place.

- Stage 2: First year of lead-paint abatement project completed in December 1999, focused on high-risk homes (children with BLLs greater than 10 µg/dL). Continuous funding was in place from 1999 to 2011 for the removal of lead in low-income housing.
- Stage 3: A lead poisoning primary prevention program commenced in 2007 and included inspections and related enforcement pertaining to identify hazards in properties who were not considered high risk (*e.g*. no children with BLLs greater than 10 µg/dL).

A clear decline in children's BLLs was observed from the surveillance data between 1993 and 2011. However, due to a limited amount of pre-1993 data, it was not possible to conclusively determine if or how much the Stage 1 interventions influenced the BLL data between October 1993 and December 1999. The complete phase-out of leaded gasoline in the US also occurred during this time interval. The influence of the Stage 2 interventions (lead hazard abatement) was difficult to identify, notably due to the increase in public awareness regarding lead hazards. Affecting all of the three (3) stages of intervention was the fluctuation in sample size over time, resulting in potential variance within the BLL data set. Shao *et al*. (2017) concluded that it is possible that once BLLs are reduced to a certain point, aggressive abatement approaches for lead paint may not contribute significantly to decreased in BLLs (Shao *et al*., 2017).

The effectiveness of home lead abatements completed between September 2016 and March 2018 was evaluated in two (2) groups of children (children with BLLs greater than 10 µg/dL, and children with BLLs between 5 and 9 µg/dL) residing in the State of Maine (Cluett *et al*., (2019). Out of a total of 351 residential inspections, 77% of these were related to children with BLLs between 5 and 9 µg/dL. Compared to children with BLLs greater than 10 µg/dL, this group of children were less likely to chew windowsills and doors and had significantly fewer paint-related sources within their homes. A positive, significant correlation was identified between BLL and lead in windowsill dust and average floor dust levels for children in the 5 to 9 µg/dL range, but not children with BLLs greater than 10 µg/dL. Following the completion of household education and abatement activities (approximately 2.8 months after the abatement was completed), follow-up samples were collected from a total of 32 children who presented pre-abatement BLLs in the 5 to 9 µg/dL range. Of these, 10 children (31%) had a decrease in BLL ranging from 15 to 40% of their baseline value, and 17 children (53%) had an observed decrease in BLL over 40% or more. Cluett *et al*. (2019) concluded that the lead abatement activities were successful in reducing BLLs in children with BLLs in the 5 to 9 µg/dL range but note that their conclusions are based on a relatively small sample size.

The impact of the Southern Nevada Childhood Lead Poisoning and Prevention Program (CLPPP) on children's BLLs was evaluated by Haboush-Deloye *et al*. (2019). Only data from when the program was in place are available, and data from when the program was no longer funded is not yet available. The South Nevada CLPPP included state-funded educational interventions at two levels – practicing pediatricians and families, and provider-outreach (in-person visits with healthcare providers serving high-risk communities) to promote blood lead screening (the costs of which were covered by the program). The program activities for outreach to pediatricians and families took place *via* health-related events, media broadcasts, community presentations, and presentations to professional organizations (medical school, teachers). The BLL data for children under the age of 6 years tested between 2006 and 2011 were evaluated. The number of children participating in BLL screening substantially increased during the program, although it was not clear whether this was due to increased awareness of pediatricians or parents. Of the 43,028 BLL data points available from the program, only 1.5% were determined to be above 5 µg/dL and less than 1% were above 10 µg/dL, suggesting that exposure levels are generally low in the population tested. The authors noted that only 5% of the children in Nevada were tested during the program, and the results are thus based on a small sample size (Haboush-Deloye *et al*., 2019).

Taylor *et al*. (2011) state that, despite the lack of evidence supporting the efficacy of educational-based interventions directed towards parents concerning the importance of personal hygiene, child mouthing behavior, and household dust, these programs are often used to address elevated BLLs in children. Although these types of interventions have, in some instances, been reported to lower BLLs among children, Taylor *et al*. (2011) indicate that it is difficult to attribute reductions in BLLs to any one individual intervention (*e.g*., hand washing versus wet mopping, *etc*.). Taylor *et al*. (2011) argue that, in addition to educational programs, more effective primary intervention strategies that directly reduce both point source and fugitive emissions are required.

5.0 TASK 4: ASSESSMENT OF HEALTH RISKS ASSOCIATED WITH ELEVATED LEAD LEVELS IN URBAN RESIDENTIAL SOILS

Understanding the relationship between soil concentrations and exposure in children is important for the assessment of potential risks and the development of environmental guidelines. This relationship can be evaluated using multiple lines of evidence, including theoretical models to predict exposure and uptake, and through consideration of empirical results generated by studies in which both environmental concentrations and exposures (*e.g.*, BLLs) were measured.

Numerous studies have characterized the relationship between BLLs and lead content in various environmental media, including soil, in both Canada and internationally. Empirical results are often used to generate a regression or slope factor relating changes in BLLs with soil or other environmental lead concentrations. Slope factors generated using empirical data reflect site-specific and study-specific exposure scenarios, and as a result there is inherent uncertainty in applying these factors to other sites. Therefore, the relationships between soil concentrations and BLLs identified within these studies were used to provide a qualitative assessment of potential risks to Winnipeg residents. Given that automobile exhaust from leaded gasoline is interpreted to be the main (past) contributor to lead content in soils of central areas of Winnipeg, this was an important consideration in the identification of comparable communities.

The qualitative assessment of health risks also considered the occurrence of areas within Winnipeg that may have unique characteristics that create increased opportunities for overall lead exposure such as proximity to highways, the presence of current or historical industrial activities, and aged housing stock which may be indicative of the presence of leaded paint and plumbing. Additional variables that were considered when evaluating exposure and interpreting risk estimates include socio-economic factors that may influence the susceptibility of an individual to lead toxicity such as nutritional deficiencies. Factors that may increase the potential for overall lead exposure and the occurrence of adverse effects are important to consider when interpreting risks related to soil concentrations for sensitive sub-populations. They may also influence the development of risk management strategies to target the most effective measures to reduce overall exposure and risks related to lead in an urban environment.

5.1 Summary of the Findings of Task 4

To evaluate the potential health risks associated with soil lead concentrations for those neighbourhoods identified as being of potential concern, the following tasks were completed:

- Blood lead modelling using the US EPA IEUBK model;
- A comparison of soil lead concentrations in the neighbourhoods of potential concern in Winnipeg with concentrations measured in soils from other urban areas;
- A review of the primary literature to identify relationships between soil lead and BLLs derived using empirical results; and,
- A high-level, qualitative evaluation of the sociodemographic characteristics and general health status of the identified neighbourhoods of potential concern.

The assumptions and algorithms used within the IEUBK model are designed to predict the likely distribution of BLLs in young children. Use of the IEUBK model for a neighbourhood -based assessment has limitations in that it assumes that all children within a given population will be exposed to homogenous levels of lead under a similar exposure scenario. In reality, there may be significant variability in the lead concentrations in media such as indoor dust and backyard soil across properties within any given neighbourhood. Recognizing this limitation, BLLs were predicted to represent the geometric mean value for children in ten (10) neighbourhoods identified as having soil lead concentrations of potential concern. The IEUBK model was run using arithmetic mean soil concentrations for each of these neighbourhoods, as well as Winnipeg-specific drinking water and outdoor air concentrations. The concentration of lead in drinking water was set as 0.17 µg/L which represents the average concentration in treated water in 2018 (City of Winnipeg, 2019d). As part of the National Air Pollution Surveillance (NAPS) program, ambient air samples are collected from cities across Canada, including Winnipeg. Samples are analyzed for particulate matter with an aerodynamic diameter less than 2.5 µm ($PM_{2.5}$). The arithmetic mean concentration of lead associated with $PM_{2.5}$ in Winnipeg from the most recent reported year (2017) was 0.002 µg/m^3 (Environmental and Climate Change Canada, 2017b). This value was selected to represent the concentration of lead in ambient outdoor air for each of the Winnipeg neighbourhoods considered. Results of this assessment indicate that predicted geometric mean BLLs for North Point Douglas and Weston were above 2 µg/dL, the value selected as a level of concern to be protective of neurodevelopmental effects in children. In addition, utilizing a standard factor to account for variability within a population, the model predicts that there is a greater than 5% probability that a child will have a BLL exceeding 2 µg/dL in each of the ten (10) neighbourhoods considered. Using the 95th percentile soil concentrations, the geometric mean BLLs were above 2 µg/dL for all neighbourhoods considered.

While these results may provide a general idea of the average neighbourhood risk potential, a more accurate method to assess risk may be to consider soil concentrations on a property by property basis. The results of the IEUBK modelling, using an ambient outdoor air concentration of 0.002 µg/m^3, a drinking water concentration of 0.17 µg/L, and standard exposure estimates associated with lead in a North American diet, indicate that a soil lead concentration of approximately 165 µg/g will result in a mean BLL of 2 µg/dL, and a soil concentration of 50 µg/g is associated with a 95% probability that a BLL will be below 2 µg/dL. Given that St. Boniface is the only neighbourhood for which sampling was conducted on residential properties, soil results from this neighbourhood were used to identify the general proportion of properties that may contain soil lead concentrations that exceed these values. There are a significant number of residential properties that contain concentrations of lead in outdoor soil that are above concentrations associated with a geometric mean BLL of 2 µg/dL (165 µg/g), and a 5% probability of exceeding a BLL of 2 µg/dL (50 µg/g). Similarly, the results of the 2010 Manitoba soil investigation indicate that the neighbourhood of North Point Douglas may also have numerous properties with soil lead concentrations that exceed these criteria. This may also be true for other Winnipeg neighbourhoods that have not been characterized with the same sampling intensity.

Overall, the results of the IEUBK modelling indicate that the potential for children's BLLs to exceed a level of concern are relatively low for many of the neighbourhoods for which soil lead results are available, particularly given that most of these areas do not have a significant active source of lead emissions. Many studies have demonstrated significant decreases in BLLs following a reduction or elimination of emissions despite the continued presence of elevated concentrations in soil. There are numerous areas of uncertainty associated with characterizing opportunities for exposure to soil contamination resulting from historical emissions. However, there is a greater potential for children to have elevated BLLs in the neighbourhoods of North Point Douglas and Weston as a result of the frequency of elevated soil lead concentrations in these areas. Given that modelling of BLLs was only conducted for those neighbourhoods that were identified as having 10% or more of samples with concentrations that exceeded the CCME guideline, there are numerous additional neighbourhoods where sampling has occurred where the potential for elevated BLLs are considered to be low.

Given the theoretical nature of modelling BLLs based on assumptions of exposure, uptake, and biokinetics, additional methods for assessing potential risks to Winnipeg residents should also be considered. This includes consideration of studies in which lead exposure has been measured *via* blood lead analysis and used to establish a correlation between BLLs and concentrations of lead in soil and other environmental media. A review of numerous studies describing the empirical association between soil lead concentrations and BLLs in children have shown significant and strong associations between the two variables on a case-by-case basis. Some models report a linear relationship between soil lead and BLLs, with slopes indicating that for every 1,000 µg/g increase in soil lead there is an increase in children's BLL of 1.3 to 1.5 µg/dL. Other studies have reported a curvilinear relationship in which BLLs increase at a much steeper rate at lower soil concentrations (1.4 µg/dL per 100 µg/g) followed by a more gradual increase at higher concentrations (0.32 µg/dL per 100 µg/g). It is important to note that relationships varied significantly across studies and other factors, including seasonal variability and child age, can have a large impact on lead exposure in children.

Overall, there is a large degree of uncertainty in utilizing empirical results and modelled relationships to predict BLLs in children. A comparison of the results using each of these approaches demonstrates that the slope predicted using the IEUBK model is greater than those derived using empirical data, indicating that BLLs may be overpredicted at incremental increases in soil lead concentrations in some circumstances. However, at soil lead concentrations below 100 µg/g, the IEUBK model predicted lower BLLs than the empirical relationships. At relatively low soil lead concentrations, the curvilinear relationships identified by Mielke *et al*. (2007), Johnson and Bretsch (2002), Zahran *et al*. (2011) may be the most applicable models for most Winnipeg neighbourhoods. These relationships demonstrate that BLLs increase at a sharper rate at soil lead concentrations below 100 µg/g, followed by a more gradual increase around 300 µg/g. Use of these relationships would predict geometric mean BLLs of greater than 2 µg/dL at concentrations below 100 µg/g, indicating potential concerns for several Winnipeg neighbourhoods; however, it is unknown if non soil-related exposures in the neighbourhoods that these relationships were based on are similar to those in Winnipeg. As a result, there is uncertainty in the application of the empirical results to predict BLLs in Winnipeg neighbourhoods.

As indicated previously, the IEUBK model is designed to predict the likely distribution of BLLs in young children. In some instances, the results of the model have been shown to be highly conservative when compared to measured BLLs. For the community of St. John's Newfoundland, soil concentrations were found to be similar or higher than those identified in areas of Winnipeg, with a 50th percentile of 148 µg/g for all soil samples combined. Blood lead levels in St. John's were predicted using the IEUBK model to be 6.5 µg/dL for housing built before 1926, with the geometric mean BLL declining in relation to property age down to 2.8 µg/dL or less. A follow-up biomonitoring study determined that the geometric mean BLL in children (less than 7 years of age) living in St. John's was 1.12 µg/dL (Health Canada, 2013b).

Contributing to the uncertainty associated with predicting BLLs and the effects of lead exposure in Winnipeg children is the relatively lower socioeconomic and health status ratings for some of the neighbourhoods identified as having elevated soil lead concentrations. This includes North Point Douglas, Weston, Daniel McIntyre, and Centennial, which share similar characteristics including lower income, lower rates of employment, lower levels of education, higher proportion of Aboriginal and visible minority residents, and lower ratings than for the overall City of Winnipeg for several indicators of health (*e.g.*, disease prevalence, birth weight, mortality rates, life expectancy).

5.2 Assessment of Potential Risks

The relationship between soil lead concentrations and BLLs was evaluated using the Integrated Exposure Uptake Biokinetic (IEUBK) model (Section 5.2.1) and empirical results generated by studies in which both environmental concentrations and BLLs were measured (Section 5.2.2).

5.2.1 Use of the IEUBK Model to Predict Blood Lead Levels in Children

The IEUBK model for Windows (IEUBKwin32 Version 1.1 Build 11) was used to predict BLLs in children in various neighbourhoods within Winnipeg and to provide an estimate of the probability that a child's or a population of children's BLL will exceed a level of concern. The IEUBK computer model is a physiologically based pharmacokinetic (PBPK) model developed by the US EPA to predict childhood lead exposure and retention. It has the ability to quantify the relationship between environmental lead concentrations in different media (*e.g.*, soil, water, air and food) to BLLs in children of different ages (0 to 84 months) (US EPA, 1994). Estimates of a likely distribution of BLLs are centered on the geometric mean concentration and can be used to calculate the probability that BLLs in children will exceed an acceptable level. A general description of the IEUBK model is provided in Section 5.2.1.1. The approach in which the model was applied to predict BLLs in children in Winnipeg is described in Section 5.2.1.2.

5.2.1.1 The IEUBK Model

The IEUBK model is recognized as a highly defensible tool for performing lead risk assessments. It has undergone rigorous peer review and empirical data supports the accuracy of its results. The model was developed to account for the unique aspects of lead exposure, bioavailability, and toxicokinetics. The model is comprised of four main sections or components which work together to predict BLLs from environmental media concentrations:

- Exposure;
- Uptake;
- Biokinetics; and,
- Variability.

These components are described below.

Exposure Component

Children may come into contact with lead in their environment in a variety of ways, depending on their daily activities and the ways in which they use their local resources (*e.g.*, yards, parks, playgrounds). The path that a chemical travels to reach an environmental medium (*e.g.*, air, soil, water, food, etc.) that a person may come into contact with is referred to as an exposure pathway. The means by which a chemical moves from the environmental medium into the body is called an exposure route. There are three (3) major exposure routes through which chemicals can enter the body: inhalation, ingestion, and dermal absorption (*i.e.*, through the skin). The IEUBK model addresses inhalation and ingestion. The likelihood of appreciable dermal absorption of inorganic lead compounds is low and is considered to be a minor route of exposure relative to inhalation and ingestion. Therefore, dermal exposure is not included in the IEUBK model (US EPA, 1994).

The exposure component of the IEUBK model uses both receptor- and media-specific (*i.e.*, soil, dust, air, water, food) intake rates in combination with environmental media concentrations to estimate total daily lead intake rates of children on a "µg lead/day" basis. Both media concentrations and receptor intake rates are controlled by the model user; therefore, "default" values and/or relationships provided by the US EPA can be supplemented with site-specific data when available. The IEUBK default receptor-specific media intake rates were based on a variety of studies that examined typical and/or national average intake rates for specific age classes of concern in the United States. In the absence of site-specific lead concentrations, such as indoor dust and indoor air data, the model has the ability to project indoor concentrations based on measured outdoor soil and air data. The medium of greatest concern at sites with lead-impacted soil is generally the soil itself. Children can be exposed to soil through incidental ingestion as a result of play, hand-to-mouth behaviour, or any other activity that involves oral contact with unclean objects. Furthermore, small children tend to have greater physical proximity to soil and dust.

The resulting estimated daily exposures of children in µg lead/day are used as input data for the uptake component of the model.

Uptake Component

The uptake component of the IEUBK model determines what proportion of a child's total daily lead intake will be transferred to the child's blood plasma (where it can be delivered to critical organ systems) and what portion will be eliminated from the body. Lead uptake can be defined as the amount of lead absorbed per unit time from both the gut and the lungs into the systemic circulation of blood (US EPA, 1994). Only a fraction of a child's total daily intake will actually enter the systemic blood flow; this fraction is referred to as the absorption fraction.

Absorption data taken from studies in humans, primates and rats suggest a non-linear relationship between lead intake and lead absorption (US EPA, 1994). Sherlock and Quinn (1986) conducted a number of diet studies of bottle-fed infants exposed to both lead in water and formula mixed with lead-impacted water. Sherlock and Quinn (1986) were able to quantify a relationship between lead intake and lead absorption. The dose dependency of lead absorption was described by a "curvilinear" relationship (US EPA, 1994). In other words, as the lead intake rate increased, the rate at which lead was absorbed into the systemic blood system began to slow down. This type of non-linear absorption kinetics is addressed by the IEUBK lead model. At higher intake rates (*i.e.*, greater than 200 µg lead/day), the relationship between lead absorption and lead intake appears to be non-linear, while at doses less than 100 to 200 µg/day, the relationship appears to be linear in nature (US EPA, 1994). It should be noted that other factors such as the specific lead compound and particle size could affect the rate of absorption at lower doses. For example, studies conducted by Barltrop and Meek (1975) illustrated that lead in a sulfide, chromate, naphthenate or octoate form was 40 to 67% less bioavailable relative to lead in the more soluble carbonate form. Table 5-1 provides the default bioavailability values used by the IEUBK model for each media of concern.

Table 5-1 Default Bioavailability Values used within the IEUBK Model		
Media of Concern	**Absorption Fraction *via* Gut**	**Absorption Fraction *via* Lungs**
Soil and Dust	30%	NA
Diet	50%	NA
Water	50%	NA
Air	NA	32% bioaccessible[a] 100% bioavailable

[a] Bioaccessible refers to the amount that reaches the alveoli of the lung.
NA Not applicable.

There are two mechanisms by which lead absorption is characterized; saturable (active) and non-saturable (passive) absorption. "Saturation" occurs when further absorption is limited by existing body burden. Uptake rates in the IEUBK model are both media- and age-dependent, while individual absorption fractions are presented for each media of concern (*i.e*., dietary, dust, soil and drinking water). When saturation effects are not occurring, the IEUBK model will estimate total absorbed lead intake by adding all media specific absorption values, where absorption from each media is equal to the age dependent intake rate multiplied by the media specific absorption fraction (US EPA, 1994). However, to more accurately reflect absorption at higher doses, the saturable mechanism of absorption is also included. Thus, the total lead absorption is given by the sum of both the active and passive mechanisms of uptake.

Biokinetic Component

The biokinetic component of the IEUBK model calculates the mass of lead in various critical body compartments over time as a result of physiologic and biochemical processes. This involves a network of differential equations used by the IEUBK model to estimate the mass of lead as a function of time within each body compartment. The differential equations used within the biokinetic model form the basis of the mass balance approach.

The biokinetic model begins by calculating the volumes and weights of each compartment within a child's body as a function of age. The transfer rates between these compartments and elimination mechanisms are then estimated and an initial BLL is calculated for a newborn child (including maternal contribution). Lead masses in each body compartment and hence BLLs are calculated for each iteration or interval of time from birth to 84 months of age (US EPA, 1994). Lead burdens are estimated for several different compartments within a child's body, including:

- Plasma-extracellular fluid (ECF);
- Red blood cells;
- Liver;
- Kidney;
- Trabecular bone;
- Cortical bone; and,
- Other soft tissue.

These particular body compartments were selected for a variety of reasons. The liver and kidney were selected as they are considered potential target sites of toxicity, while bone has a potential to be a major area for lead accumulation (US EPA, 1994). The whole blood consists of two compartments, red blood cells and the extracellular fluid (ECF). It is assumed that the nervous system would be well perfused by blood.

The IEUBK model operates under the assumption that lead is transferred between the ECF compartment and most other compartments *via* first-order kinetics and at a rate of transport that is independent of compartment lead concentrations. The only transfer mechanism that is dependent on concentration is the transfer rate between plasma and red blood cells. The IEUBK model assumes that a lead saturation level does exist for red blood cells and therefore, this transfer coefficient helps to govern the age-dependent accumulation of lead in various compartments (US EPA, 1994).

The lead mass for each body compartment of a newborn child is the starting point for the biokinetic algorithm. The masses of each compartment are calculated for each time step from birth to 84 months of age; the child's BLL is then calculated as the average monthly value over the number of time intervals in one month (US EPA, 1994).

Variability Component

Variability in BLLs will exist in any given population of children even if all individuals within that population are exposed to similar levels of lead. There are many reasons why different BLLs may exist among a group of similarly exposed children. These include biological and behavioural variability, differences in food consumption rates, and variability, reproducibility and analytical errors within environmental lead measurements. The probability distribution component of the IEUBK model addresses variability of BLLs associated with a typical child or a population of children. It should be emphasized that the IEUBK model does not address variability in BLLs as a result of substantially different intake rates among children; rather, it addresses the variability observed within a group of similarly exposed individuals.

This component of the IEUBK model uses the predicted population geometric mean BLL as estimated by the previous components of the model and calculates a lognormal probability distribution of BLLs centered on this estimate. The probability distribution is created by the application of a geometric standard deviation (GSD) that is based on empirical studies of lead-exposed children. By generating a probability distribution of BLLs, the model is able to calculate the probability that a population of exposed children's BLLs will exceed a selected level of concern (*e.g.*, set at a less-than 5% probability of exceeding 2 µg/dL). The GSD recommended for use with the IEUBK model is 1.6. This value is based on a series of empirical studies of several specific sites throughout North America. A number of statistical methods were used to derive and verify this GSD and US EPA recommends that the default value of 1.6 be employed unless there are site-specific empirical studies available.

The predicted distribution of BLLs can also be used to "back-calculate" a soil lead level that contributes to a benchmark "exceedance" of a particular BLL (given other sources of exposure).

Summary of IEUBK Model

The IEUBK model has become a standard tool for performing lead risk assessments. Variants of the IEUBK model have been developed that address uncertainty associated with model variables (*e.g.*, Lee *et al*., 1995). However, the IEUBK model provides the most scientific, widely available method for estimating the risk of exceeding benchmark BLLs as well as estimating environmental concentrations of lead that may result in elevated BLLs. A number of studies have confirmed the reliability of the IEUBK model, assuming appropriate inputs, as a reasonable means of estimating criteria by comparing the model's results with empirical blood lead data (*e.g.*, Hogan *et al*., 1998; Zaragoza and Hogan, 1998).

5.2.1.2 Concentrations used in the IEUBK Model to Predict Blood Lead Levels in Children in Winnipeg

The IEUBK model was used to predict BLLs for children living in ten (10) Winnipeg neighbourhoods identified in Section 2.1.4 as being potential areas of concern. Each of these neighbourhoods were identified during the data review as having more than 10% of soil samples with lead concentrations above the CCME guideline of 140 µg/g for residential soils. For comparative purposes, a Background Soil scenario was also considered, where BLLs were predicted using a background soil concentration of 10 µg/g, which represents the arithmetic mean lead concentration in glacial tills from across Canada (Health Canada, 2013a).

The model's default exposure parameters and risk characterization assumptions were generally maintained, while environmental lead concentrations representative of conditions in Winnipeg were utilized. This allowed for the prediction of BLLs that were reflective of certain site-specific concentrations of lead in Winnipeg, while still relying on the widely accepted approaches used within the IEUBK model.

Use of the IEUBK model as a means of predicting the fraction of children in a population that may exceed a BLL of concern assumes that all individuals are subject to similar exposure conditions. Individuals within this population that may be exposed to significantly higher concentrations, particularly for prolonged periods (*e.g.*, a home with elevated levels in a backyard play area) may be subject to higher levels of lead exposure. Use of lead concentrations based on arithmetic means is intended to provide a general representation of the geometric mean BLL in children within a population and the fraction of children which may have BLLs in excess of a level of concern. For the purposes of the current exercise, children within each of the neighbourhoods selected for further consideration were assumed to be a population of similarly exposed individuals.

Although the IEUBK default BLL of concern is 10 µg/dL, this is not considered to be reflective of the current scientific understanding of the toxicity of lead in children. As a result, the BLL selected to identify the probability that an individual, or proportion of a population, may exceed a level of concern was 2 µg/dL as this represents a reasonable estimate of the level associated with a 1-point decrement in IQ (JECFA, 2011). As described in Section 4.2.2.2, the use of a BLL of concern based on a 1-point decrement in IQ is associated with a potentially high degree of variability, which must be considered in interpreting potential lead exposure risks. This value should be considered as a *de minimis* population-level effect which could likely never be detected in an individual child (SNC Lavalin, 2012).

As a result of factors such as reduced environmental deposition of lead and the reduction/elimination of lead solder in the canning process, concentrations of lead in supermarket food items have declined significantly over the past several years. To address this reduction in potential lead exposure, the US EPA has provided predicted daily lead exposures for children associated with the consumption of dietary items based on the 1995 to 2003 US Food and Drug Administration (FDA) total dietary study (TDS) and food consumption data collected by the CDC. These updated dietary lead intake values are significantly lower than the previous IEUBK default values which were based on US FDA food monitoring data collected in the late 1980s.

The reduced opportunity for lead exposure has also affected the typical BLL in mothers at childbirth. Given that the IEUBK model considers the influence of lead transferred from the mother to the fetus *in utero*, use of the most applicable maternal BLL is important for the prediction of BLLs in children. The US EPA (2017) has recommended that the default value for "*Mother's Blood Lead Concentration at Childbirth*" is adjusted from 1.0 µg/dL to 0.6 µg/dL to reflect the results of the NHANES 2009-2014 data for women 17-45 years of age.

The default exposure parameters used in the IEUBK model are presented in Table 5-2.

Table 5-2 Default Exposure Parameters Used in the IEUBK Model

Exposure Parameter	***Receptor Age Categories (Years)***						
	0-1	***1-2***	***2-3***	***3-4***	***4-5***	***5-6***	***6-7***
Inhalation Pathway							
Ventilation Rate (m^3/day)	2	3	5	5	5	7	7
Time Spent Outdoors (hrs/ day)	1	2	3	4	4	4	4
Bioavailability (%)	32						
Percentage of Lead from Outdoor Air in Indoor Air (%)	30						
Body Weights (kg)	7.4	11.4	13.4	15.7	18.2	20.4	22.3
Drinking Water Pathway							
Consumption Rate (L/day)	0.2	0.5	0.52	0.53	0.55	0.58	0.59
Bioavailability (%)	50						
Soil/ Dust Ingestion Pathway							
Soil + Dust Ingestion Rate (g/day)	0.085	0.135	0.135	0.135	0.100	0.090	0.085
Bioavailability in Soil (%)	30						
Bioavailability in Dust (%)	30						
Soil/Dust Weighting Factor (% Soil)	45						
Food Consumption Pathway							
Dietary Lead Intake (µg Pb/day)	2.26	1.96	2.13	2.04	1.95	2.05	2.22
Bioavailability (%)	50						

In addition to those values presented in Table 5-2, the use of the IEUBK model to predict BLLs in children included site-specific levels of lead in outdoor soil, outdoor air, and drinking water (Table 5-3).

Outdoor and Indoor Air

As part of the National Air Pollution Surveillance (NAPS) program, ambient air samples are collected from cities across Canada, including Winnipeg. Samples are analyzed for particulate matter with an aerodynamic diameter less than 2.5 µm ($PM_{2.5}$). The arithmetic mean concentration of lead associated with $PM_{2.5}$ in Winnipeg from the most recent reported year (2017) was 0.002 µg/m^3 (Environmental and Climate Change Canada, 2017b). This value was selected to represent the concentration of lead in ambient outdoor air for each of the Winnipeg neighbourhoods considered. Since indoor air concentrations were not measured, the IEUBK default assumption was adopted in which concentrations of lead in indoor air are assumed to be 30% of those measured in outdoor air.

Outdoor Soil and Indoor Dust

To provide a general indication of the estimated BLLs for children in each of the Winnipeg neighbourhoods identified as being of potential concern based on soil data, the arithmetic mean soil concentrations were calculated using the results of the investigations conducted by Manitoba Conservation (2010) and the University of Manitoba (2018).

The IEUBK model includes the Multiple Source Analysis (MSA) module to predict concentrations of lead in indoor dust. This involves assigning a value to represent the mass fraction (MSD) of house dust that is derived from outdoor soil. The IEUBK default value for MSD is 0.70 g soil/g dust. In addition to the contribution of outdoor soil to indoor dust lead levels, the contribution of impacted outdoor air is also considered in the MSA. An additive increment of 100 µg/g of lead in indoor dust for every 1 µg/m^3 of lead in outdoor air is added to the contribution from outdoor soil. For example, for a given scenario in which the concentration of lead in outdoor soil is 110 µg/g and the concentration in outdoor air is 0.002 µg/m^3, the predicted indoor dust concentration would be 77.2 µg/g ((110 µg/g x 0.7) + (100 µg/g x 0.002)).

Drinking Water

The IEUBK default value for lead in drinking water is 4 µg/L. However, the City of Winnipeg distribution system water quality test results are available for lead in water that has passed through treatment (City of Winnipeg, 2019d). The average concentration of lead in treated water as measured from January 1 to December 31, 2018 was reported to be 0.17 µg/L, with a range of <0.05 to 1.8 µg/L (City of Winnipeg, 2019d). It is estimated that approximately 87% of homes in the City of Winnipeg do not have lead pipes (City of Winnipeg, 2019b), therefore, use of an average concentration of 0.17 µg/L is likely representative of exposure for the majority of residents. However, it should be recognized that exposures related to drinking water may be underestimated for children living in homes with pipes or fixtures containing lead.

Table 5-3 Environmental Media Concentrations used within the IEUBK Model to Predict BLLs

Neighbourhood	Outdoor Soil (µg/g)[a]	Indoor Dust (µg/g)[b]	Outdoor Air (µg/m^3)[c]	Indoor Air (µg/m^3)[d]	Drinking Water (µg/L)[e]
Centennial	110	77.2	0.002	0.0006	0.17
Daniel McIntyre	142	99.6	0.002	0.0006	0.17
Glenelm/Chalmers	71.6	50.3	0.002	0.0006	0.17
North Point Douglas	473	331	0.002	0.0006	0.17
River/Osborne	60.4	42.5	0.002	0.0006	0.17
Sargent Park	93.8	65.9	0.002	0.0006	0.17
St. Boniface	87.8	61.7	0.002	0.0006	0.17
West End	101	70.9	0.002	0.0006	0.17
Weston	224	157	0.002	0.0006	0.17
Wolseley/Minto	74.4	52.3	0.002	0.0006	0.17
Background Soil	10[f]	7.2	0.002	0.0006	0.17

a Represents the arithmetic mean soil concentration for all samples collected by Manitoba Conservation (2010) and University of Manitoba (2017) for each neighbourhood.
b Calculated by the IEUBK model using the MSA module.
c Represents the arithmetic mean concentration measured in air associated with the $PM_{2.5}$ component from samples collected in Winnipeg in 2017 (Environment and Climate Change Canada, 2017b).
d Calculated by the IEUBK model as 30% of the outdoor air concentration.
e Represents the average concentration of lead in treated drinking water in Winnipeg in 2018 (City of Winnipeg, 2019d).
f Concentration represents the arithmetic mean background soil concentration in glacial tills from across Canada (Health Canada, 2013a).

5.2.1.3 Predicted Blood Lead Levels in Children in Winnipeg

Using the IEUBK model, BLLs were predicted for receptors in seven (7) age categories for ten (10) Winnipeg neighbourhoods. The overall geometric mean BLLs for children of all ages in North Point Douglas (4.7 µg/dL) and Weston (2.6 µg/dL) were above 2 µg/dL (Table 5-4). Geometric mean BLLs for all other neighbourhoods were below 2 µg/dL. The highest predicted BLLs were for the age group of 1 to 2 years, primarily as a result of the high soil/dust ingestion rate relative to body weight for children of this age. In North Point Douglas, the predicted BLL for children age 1 to 2 years was 6.1 µg/dL.

In addition to the geometric mean BLLs, 95th percentile values were also calculated for each neighbourhood. In Table 5-4, the 95th percentile BLLs for each neighbourhood exceeded a level of concern of 2 µg/dL and were calculated using the following equation as recommended by U.S. EPA (2002):

$$X_{95} = GM \times GSD^{Z_{95}}$$

where:

X_{95}	=	Blood lead level at the 95th percentile (µg/dL)
GM	=	Geometric mean blood lead level (µg/dL)
GSD	=	Geometric standard deviation of the distribution (1.6)
Z_{95}	=	Z-score corresponding to the 95th percentile of the standard normal cumulative distribution (1.645)

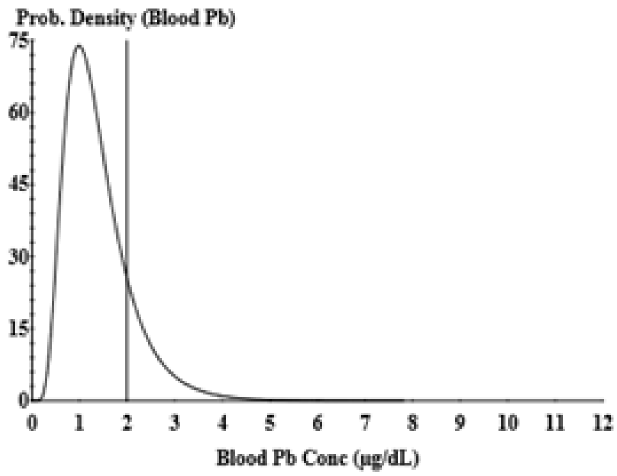
The probabilities of exceeding a BLL of concern of 2 µg/dL at the arithmetic mean soil concentration for each of the ten (10) neighbourhoods are also presented in Table 5-4. The predicted probability density is developed assuming a GSD of 1.6. This value considers biological and behavioral differences in receptors, variability in repeat sampling, variability resulting from sampling locations, and analytical variability and was developed using the results of empirical studies where both blood lead and environmental lead concentrations were measured (US EPA, 2002). It is unclear if this GSD continues to accurately reflect normal variability given the continuing decline in exposures as reflected in national blood lead monitoring. The model will allow for the use of a GSD within the range of 1.3 to 1.8 but does not recommend that users deviate from the default value without scientifically defensible studies that can be used to develop a more applicable site-specific value.

Using a background soil concentration of 10 µg/g while maintaining all other environmental lead concentrations as used for each of the ten (10) Winnipeg neighbourhoods, the geometric mean BLL was predicted to be 0.52 µg/dL. This is similar to the results of the 2016-2017 Canada Health Measures Survey which reported measured geometric mean BLLs of 0.56 and 0.54 µg/dL for Canadian children ages 3-5 and 6-11 years, respectively. These results are considered to be reflective of the overall Canadian population, including areas with different population densities (Health Canada, 2019b). Regional soil lead concentrations are anticipated to be highly variable among those populations selected for inclusion in the national survey. The background soil concentration of 10 µg/g is representative of natural conditions rather than regional background concentrations for urban environments where soil conditions have been influenced by anthropogenic activities. As a result, a comparison of the predicted BLLs for the Winnipeg neighbourhoods to those predicted under the Background Soil scenario may overestimate the differences in BLLs in Winnipeg relative to the majority of the Canadian population.

Table 5-4	Predicted Blood Lead Levels in Winnipeg Neighbourhoods of Potential Concern (µg/dL)										
Age Categories (years)	**Background Soil**	**Centennial**	**Daniel McIntyre**	**Glenelm/ Chalmers**	**North Point Douglas**	**River/ Osborne**	**Sargent Park**	**St. Boniface**	**West End**	**Weston**	**Wolseley/ Minto**
0.5 to 1	0.7	1.8	**2.2**	1.4	**5.4**	1.3	1.7	1.6	1.7	**3.0**	1.5
1 to 2	0.6	1.9	**2.3**	1.4	**6.1**	1.3	1.7	1.6	1.8	**3.3**	1.5
2 to 3	0.5	1.8	**2.1**	1.3	**5.7**	1.2	1.6	1.5	1.6	**3.1**	1.3
3 to 4	0.5	1.6	2.0	1.2	**5.4**	1.1	1.5	1.4	1.5	**2.9**	1.2
4 to 5	0.4	1.3	1.6	1.0	**4.4**	0.9	1.2	1.1	1.3	**2.3**	1.0
5 to 6	0.4	1.1	1.3	0.8	**3.6**	0.8	1.0	1.0	1.1	1.9	0.9
6 to 7	0.4	1.0	1.2	0.8	**3.1**	0.7	0.9	0.9	0.9	1.7	0.8
Geometric Mean	0.52	1.5	1.8	1.1	**4.7**	1.0	1.3	1.3	1.4	**2.6**	1.2
95^{th} Percentile BLL	1.1	**3.3**	**3.9**	**2.4**	**10**	**2.2**	**2.8**	**2.8**	**3.0**	**5.6**	**2.6**
Probability of exceeding a BLL of 2 µg/dL	0.20%	27%	41%	11%	97%	7.6%	20%	17%	23%	70%	12%

Bolded BLLs exceed the level of concern of 2 µg/dL.

Using the neighbourhood of St. Boniface as an example (since it is the only neighbourhood where soil samples were collected from residential properties), assuming homogeneous concentrations of lead in environmental media and diet, and incorporating the GSD of 1.6 to account for variability, the probability density for St. Boniface children shows that approximately 17% of the population of children up to the age of seven are predicted to have BLLs greater than the level of concern (2 µg/dL) assuming that they are all exposed to a soil concentration similar to the arithmetic mean (87 µg/g) (Figure 5-1).



Geometric Mean BLL = 1.3 µg/dL
% Above 2 µg/dL= 17
% Below 2 µg/dL = 83

BLL of concern = 2 µg/dL
GSD = 1.6

Figure 5-1 Probability Density of Blood Lead Concentrations (µg/dL) in St. Boniface Children Relative to a Blood Lead Level of Concern of 2 µg/dL at the Arithmetic Mean Soil Concentration (87 µg/g)

Given that there was a high degree of variability in soil lead concentrations measured throughout St. Boniface (4.86 to 1,630 µg/g) and other Winnipeg neighbourhoods, the use of the IEUBK model to predict BLLs using a mean soil concentration may provide a general indication of theoretical BLLs in children but is not regarded as providing an accurate representation of BLLs throughout the neighbourhood. Using the 5th and 95th percentile soil concentrations for St. Boniface (8.87 and 246 µg/g, respectively), the predicted geometric mean BLLs would range from 0.51 to 2.8 µg/dL.

Soil and dust contributions were the dominant source of BLLs for receptors of all age categories, followed by diet (Table 5-5). For neighbourhoods with higher soil lead concentrations, soil and dust represented a higher percentage of total exposure (with a maximum of 94% for children aged 1 to 2 years in North Point Douglas). Contributions from air and water were minor relative to the other exposure sources (Figure 5-2).

Table 5-5	Percent Contribution of Each Exposure Pathway to Total Lead Exposure for St. Boniface children as Predicted by the IEUBK Model			
Age Categories (years)	**Air**	**Diet**	**Water**	**Soil and Dust**
0.5 to 1	0.000%	38%	0.55%	62%
1 to 2	0.026%	25%	1.1%	74%
2 to 3	0.025%	26%	1.1%	73%
3 to 4	0.026%	25%	1.1%	73%
4 to 5	0.032%	30%	1.5%	68%
5 to 6	0.067%	34%	1.6%	65%
6 to 7	0.067%	37%	1.7%	62%

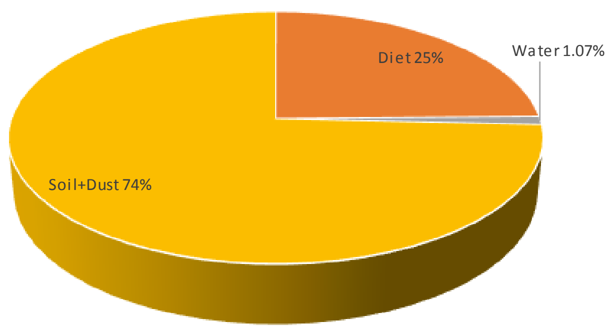


Figure 5-2 Contribution of Environmental Media to Lead Exposure in Children Aged 1 to 2 Years in St. Boniface as Predicted using the IEUBK Model

A near-linear relationship between soil lead concentrations and BLLs was predicted using the IEUBK model across the range of mean soil concentrations for each of the selected neighbourhoods, with a slightly higher rate of BLL increase at lower soil concentrations (Figure 5-3). Although the model assumes that a curvilinear relationship will occur at higher levels of exposure (*i.e.*, >200 µg lead/day), predicted exposure levels in children of all ages in each neighbourhood were well below levels at which this relationship is estimated to occur. The highest predicted exposure (15.5 µg/day) was for children aged 3 to 4 years from North Point Douglas.

Given that there are areas in Winnipeg with homes that are known to include lead-containing plumbing and fixtures, the effect of assuming higher concentrations of lead in drinking water on the predicted BLLs was evaluated. While the slope of the relationship between varying soil lead concentrations and BLLs remains consistent, the intercept (or starting point) is dependent on the other sources of exposure (*e.g.*, drinking water, air, diet, and maternal transfer) that were assumed to be constant. Figure 5-3 illustrates the relationship between soil lead and BLLs using the average concentration of lead in drinking water at the municipal source (0.17 µg/L) as well as at the current Health Canada drinking water guideline (5 µg/L), the previous guideline (10 µg/L), and an elevated concentration that may not be uncommon for homes with residential plumbing (20 µg/L). For the neighbourhood of North Point Douglas, the predicted geometric mean BLL would increase from 4.7 µg/dL at a drinking water concentration of 0.17 µg/L, to 5.1 µg/dL at a drinking water concentration of 5 µg/L. With increases of the drinking water concentration to 10 and 20 µg/L, the predicted geometric mean BLLs would increase to 5.4 and 6.1 µg/dL, respectively. This represents a BLL increase of approximately 0.3 µg/dL for every incremental increase of 5 µg/L in drinking water concentration across this range.

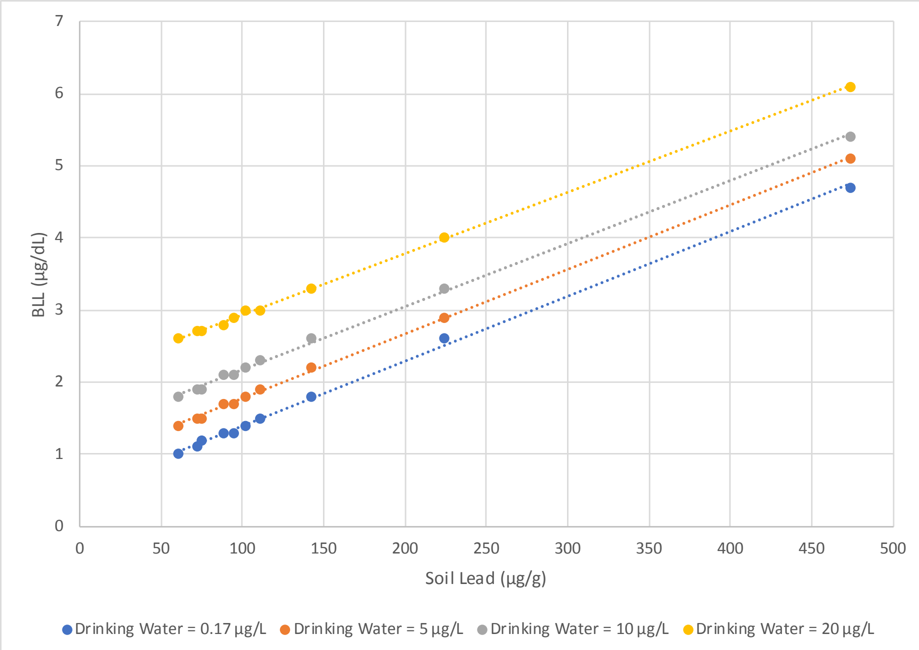
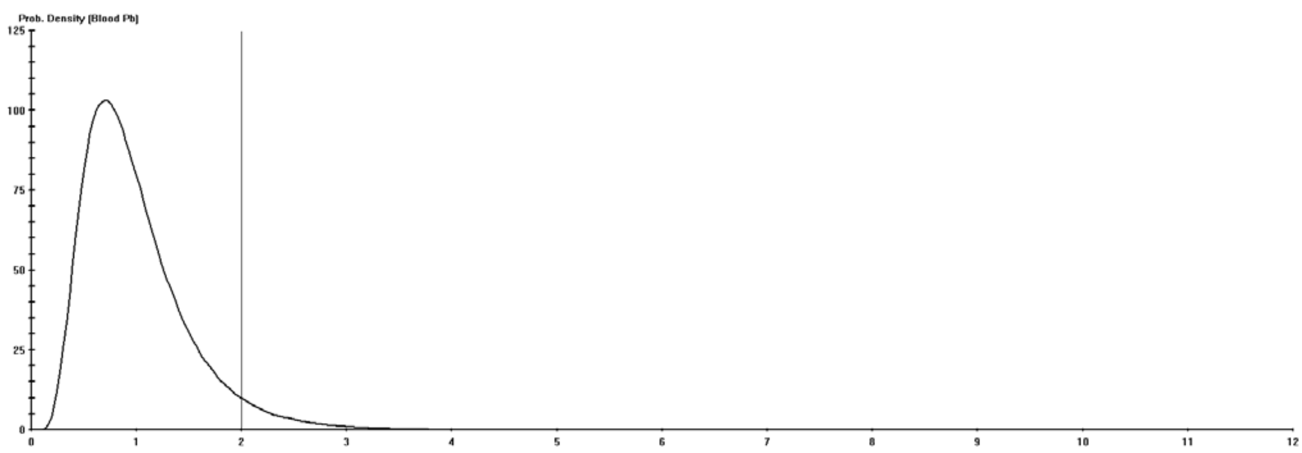


Figure 5-3 Predicted Geometric Mean Blood Lead Levels at Arithmetic Mean Soil Concentrations Across Winnipeg Neighbourhoods using Four Different Drinking Water Concentrations

In addition to predicting BLLs for each of the neighbourhoods of potential concern, the IEUBK model was used to calculate a soil concentration (50 µg/g) protective of a 5% probability of exceeding a BLL of 2 µg/dL in which concentrations of lead in air and drinking water, and total dietary lead intake, remained constant (Figure 5-3). The model also estimated that a soil concentration of 165 µg/g is associated with a geometric mean BLL of 2 µg/dL.



Geometric Mean BLL = 0.92 µg/dL
% Above 2 µg/dL= 4.9
% Below 2 µg/dL = 95

BLL of concern = 2 µg/dL
GSD = 1.6

Figure 5-3 Probability Density of Blood Lead Levels Associated with a 5% Probability of Exceeding a Blood Lead Level of Concern of 2 µg/dL (Outdoor Soil Concentration of 50 µg/g)

Using the results of the University of Manitoba soil investigation for only those samples collected from residential properties (*i.e.*, excluding samples collected from commercial properties, parks, playgrounds, etc.), approximately 50% of the sampled residential properties contained concentrations of lead that exceeded 50 µg/g, while approximately 12% exceeded a concentration of 165 µg/g (Figure 5-4). Lead concentrations for some properties are based on samples that were collected from gardens that included amended soils which are likely to have significantly lower concentrations than areas that were exposed to historical deposition. In addition, samples were collected from a depth of 0 to 10 cm during this study. Given that lead is not expected to appreciably migrate through the soil column over time, sampling at this depth may have resulted in a dilution of the more heavily impacted surface soils with those found at deeper depths that were not historically exposed to deposited particulates. As a result, this comparison may have underestimated the number of properties within St. Boniface that have lead concentrations above these criteria in non-amended soils.

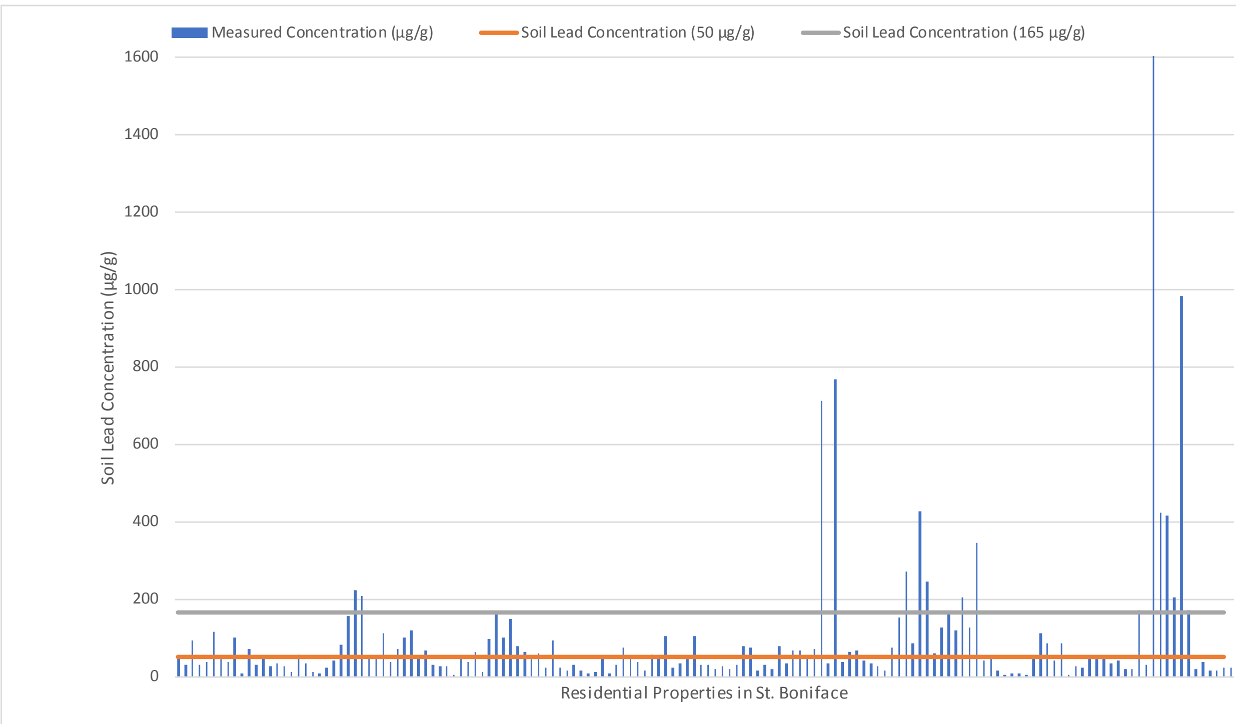


Figure 5-4 Concentrations of Lead on Residential Properties in St. Boniface Relative to Soil Concentrations Protective of a Geometric Mean BLL of 2 µg/dL (165 µg/g) and a 5% Probability of Exceeding a Blood Lead Level of Concern of 2 µg/dL (50 µg/g)

The number of sample locations from residential boulevards in the neighbourhood of North Point Douglas with concentrations in excess of these criteria were also examined. The results of the 2010 Manitoba soil investigation were considered in this comparison since these samples were collected at a depth of 0-2.5 or 0-5 cm which is considered to be more representative of soils that may be encountered on a regular basis relative to those samples collected at 0-7.5 cm during the 2019 investigation. Arithmetic mean soil lead concentrations in North Point Douglas were also notably higher at the 0-2.5 or 0-5 cm range (473 µg/g) in the 2010 investigation relative to the 0-7.5 cm range (195 µg/g) in the 2019 investigation. For those locations where samples were collected at both 2.5 and 5 cm, the 2.5 cm sample was selected to represent the lead soil concentration at that location. This comparison indicated that 21 of 23 locations (91%)

contained concentrations of lead that exceeded 50 µg/g, while 17 of 23 (74%) locations exceeded a concentration of 165 µg/g (Figure 5-5). Assuming that concentrations measured along these boulevards are reflective of conditions on residential properties, a significant proportion of this neighbourhood may contain soil lead concentrations that exceed these criteria.

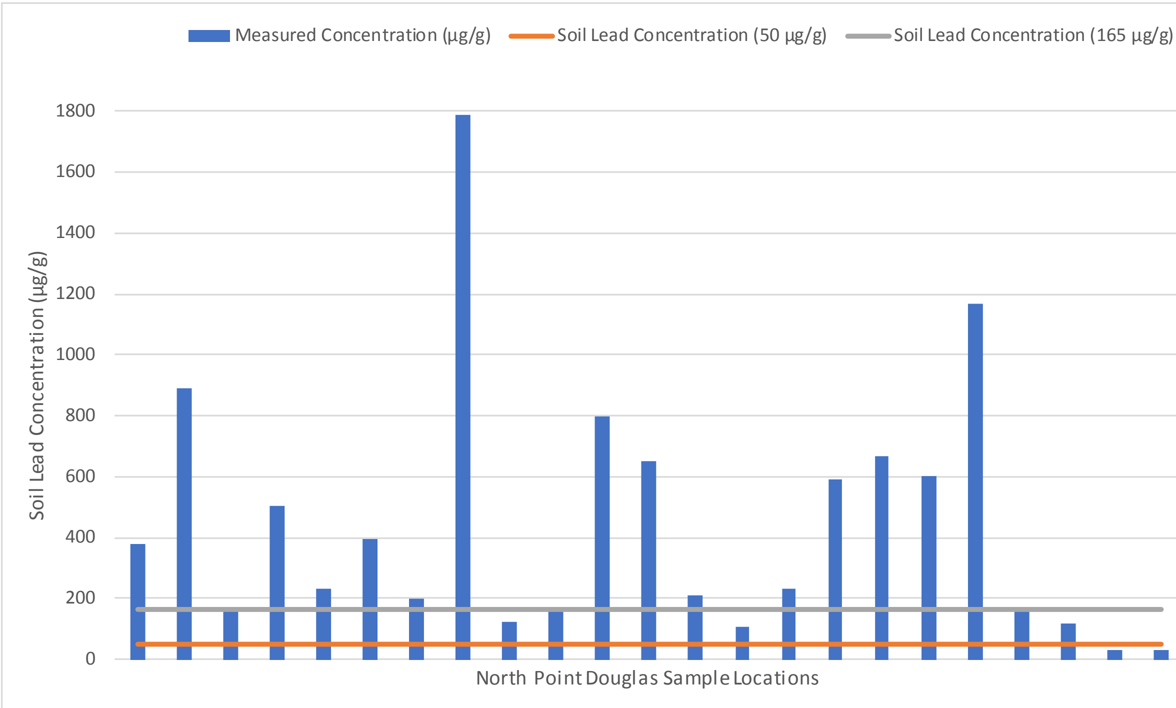


Figure 5-5 Concentrations of Lead on Boulevards in North Point Douglas Relative to Soil Concentrations Protective of a Geometric Mean BLL of 2 µg/dL (165 µg/g) and a 5% Probability of Exceeding a Blood Lead Level of Concern of 2 µg/dL (50 µg/g)

5.2.1.4 Conclusions of the IEUBK Modelling

Use of the IEUBK model for a neighbourhood -based assessment has limitations in that it assumes that all children within a given population will be exposed to homogenous levels of lead under a similar exposure scenario. In reality, there may be significant variability in the lead concentrations in media such as indoor dust and backyard soil across properties within the neighbourhood. Recognizing this limitation, BLLs were predicted to represent the geometric mean value for children in ten (10) neighbourhoods identified as having soil lead concentrations of potential concern. Results of this assessment indicate that geometric mean BLLs for North Point Douglas and Weston were above 2 µg/dL, and that there is a greater than 5% probability that a child will have a BLL exceeding 2 µg/dL in each of the ten (10) neighbourhoods considered. Using the 95th percentile soil concentrations, the geometric mean BLLs were above 2 µg/dL for all ten (10) neighbourhoods considered.

Overall, the results of the IEUBK modelling indicate that the potential for children's BLLs to exceed a level of concern are relatively low for many of the neighbourhoods for which soil lead results are available, particularly given that most of these areas do not have a significant active source of lead emissions. Many studies have demonstrated significant decreases in BLLs following a reduction or elimination of emissions despite the continued presence of elevated concentrations in soil. There are numerous areas of uncertainty associated with characterizing opportunities for exposure to soil contamination resulting from historical emissions. However, there is a greater potential for children to have elevated BLLs in the neighbourhoods of North Point Douglas and Weston as a result of the frequency of elevated soil lead concentrations in these areas.

Given that modelling of BLLs was only conducted for those neighbourhoods that were identified as having 10% or more of samples with concentrations that exceeded the CCME guideline, there are numerous additional neighbourhoods where sampling has occurred where the potential for elevated BLLs are considered to be low. It must be noted that the available sampling data for these and most other Winnipeg neighbourhoods may not be representative of soil concentrations on residential properties throughout these areas. Sampling conducted by the Province was restricted to public lands including boulevards, parks, and schools. In particular, sampling from the Weston neighbourhood was heavily focused on the Weston Elementary school yard which may or may not be representative of the variability of concentrations throughout this neighbourhood. The soil investigation conducted by the University of Manitoba for the neighbourhood of St. Boniface consisted of the collection of 174 samples, including sampling on approximately 150 residential properties. As a result, the variability in soil lead concentrations in this neighbourhood is probably more accurately characterized than for other neighbourhoods.

While these results may provide a general idea of the average neighbourhood risk potential, a more accurate method to assess risk may be to consider soil concentrations on a property by property basis. The results of the IEUBK modelling using an ambient outdoor air concentration of 0.002 µg/m^3, a drinking water concentration of 0.17 µg/L, and the standard exposure estimates associated with lead in a North American diet, indicates that a soil lead concentration of approximately 165 µg/g will result in a mean BLL of 2 µg/dL, and a concentration of 50 µg/g will result in a 5% probability of exceeding a BLL of 2 µg/dL. Using the results of the St. Boniface soil investigation, there are a significant number of residential properties that contain concentrations of lead in outdoor soil that are above concentrations associated with a geometric mean BLL of 2 µg/dL (165 µg/g), and a 5% probability of exceeding a BLL of 2 µg/dL (50 µg/g). Similarly, the results of the 2010 Manitoba soil investigation indicate that the neighbourhood of North Point Douglas may also have numerous properties with soil lead concentrations that exceed these criteria. This may also be true for other Winnipeg neighbourhoods that have not been characterized with the same sampling intensity.

As indicated previously, the IEUBK model is designed to predict the likely distribution of BLLs in young children exposed to lead through various exposure pathways. In some instances, the results of the model have been shown to be highly conservative when compared to measured BLLs. For the community of St. John's Newfoundland, soil concentrations were found to be similar or higher than those identified in areas of Winnipeg, with a 50th percentile of 148 µg/g for all soil samples combined. Blood lead levels in St. John's were predicted using the IEUBK model to be 6.5 µg/dL for housing built before 1926, with the geometric mean BLL declining in relation to property age down to 2.8 µg/dL or less. A follow-up biomonitoring study determined that the geometric mean BLL in children (less than 7 years of age) living in St. John's was 1.12 µg/dL (Health Canada, 2013b).

Given the theoretical nature of modelling BLLs based on assumptions of exposure, uptake, and biokinetics, additional methods for assessing potential risks to Winnipeg residents should also be considered. This includes consideration of studies in which lead exposure has been measured *via* blood lead analysis and used to establish a correlation between BLLs and concentrations of lead in soil and other environmental media.

5.2.2 Empirical Evidence of the Relationship Between Lead in Soil and Blood Lead Levels

Understanding the relationship between soil lead concentrations and corresponding BLLs in children is important for assessing potential risks and developing risk management strategies. A review of the primary literature was conducted to identify studies in which an empirical approach was used to investigate this relationship. This review focused on studies published after the year 2000 to characterize relevant, present-day exposures that are comparable to current conditions in the City of Winnipeg. These more recent investigations are reflective of opportunities for lead exposure following the phasing-out of lead from fuel, paint, solder, and plumbing components, as well as ongoing improvements in emissions management. Studies that included soil lead measurements in urban areas were considered separately from those that focused on communities that were impacted by a distinct point source. Emphasis was placed on studies that included soil measurements for residential properties, schools, play areas, or parks to ensure that the data were relevant to the assessment of risks for the Winnipeg neighbourhoods under examination. Additional details regarding these studies are available in Tables C-1 and C-2 within Appendix C. A summary of studies with available soil lead data and measured or predicted BLLs is provided in Table 5-6.

Table 5-6 Summary of Identified Studies Examining Soil Lead Concentrations and Predicted or Measured Blood Lead Levels				
Location	**Sample Characteristics**	**Soil Results**	**BLL**	**Reference**
Residential and play areas, Philadelphia, Pennsylvania	N=38 Sample depth: 1 -2 cm BLL N=49 children from sampled residences	Total lead concentrations: 659 µg/g (median) 58 to 2821 µg/g (range) Bioaccessible lead concentrations: 681 µg/g (median) 47 to 2,567 µg/g (range)	Measured BLL. Mean 3 µg/dL; median 1.8 µg/dL, range 0.3 to 9.8 µg/dL	(Bradham *et al*., 2017)
Sydney estuary region, Sydney, Australia	N=341 soil samples Sample depth: 0 – 2.5 cm	Residential areas: 210 µg/g (mean) 85 µg/g (geometric mean) Open space land use: mean 71 µg/g; geometric mean 42 µg/g)	Predicted BLL: IEUBK model used, assumed absolute bioavailability of 34%. BLL estimated to range from 1.3 to 16.8 µg/dL, geometric mean 2.0 µg/dL	(Laidlaw *et al*., 2017)
Residential areas, Metropolitan Melbourne, Australia	N=250, Sample depth: 0-2 cm	Mean 193 µg/g, median 110 µg/g, geometric mean 108 µg/g, range 8-3341 µg/g	Predicted BLL: IEUBK model used, assumed absolute bioavailability of 34%. Mean 2.9 µg/dL, geometric mean 2.5 µg/dL, range 1.3 to 22.5 µg/dL	(Laidlaw *et al*., 2018)
Residential soils near five historic smelter operations, Pueblo (Bessemer), Colorado	N=31 samples collected from three different zones representing distances from smelters Sample depth: 0-5 cm N=240 children (ages -0-11 years) evaluated for BLL	126 µg/g (median, all zones) 12 to 10,011 µg/g (all zones)	Measured BLL. 18/240 children (7.5%) had BLL > 5 µg/dL Mean and geometric mean not determined due to detection limit issues	(Diawara *et al*., 2018)
Residential soils, France (various locations)	Soil N=315, depth not clear BLL N=484 children (ages 6-months to 6-yr) in France	Mean 33.9 µg/g, median 27.2 µg/g	Measured BLL. Geometric BLL in children (ages 6-months to 6-yr) determined to be 1.38 µg/dL). 95th percentile BLL (population weighted) was 3.28 µg/dL	(Etchevers *et al.*, 2015)
Residential soils, Syracuse, New York	N=194 samples, Sample depth: 0-10 cm Sample cores collected BLL. N=12,228 blood samples from children ages 0-6 years, from Onondaga County Health Department	Geometric mean 80 µg/g. 95% of samples presented concentrations in the range of 20-800 µg/g	Measured BLL. Over 27.6% of the children sampled (n=3375) had BLL above 10 µg/dL. Geometric mean between 4 to 6 µg/dL (estimated)	(Johnson and Bretsch, 2002)
Residential soils, Flint, Michigan	Soil N=248 samples, Sample depth: 7.6-10 cm from lawns, and up to 18 cm in gardens	Inner city: range 126-222 µg/g Within City boundary: range 0 to 222 µg/g	Measured BLL. BLL – only percentages at or above 5 µg/dL discussed. 3.6% of children in Flint had BLL greater than 5 µg/dL before 2014, which rose to 7% in 2014	(Laidlaw *et al.*, 2016)

Table 5-6 Summary of Identified Studies Examining Soil Lead Concentrations and Predicted or Measured Blood Lead Levels

Location	Sample Characteristics	Soil Results	BLL	Reference
Sydney estuary (Port Jackson) catchment area, Sydney Australia in 2011	N=341, sample depth 0 to 2.5 cm	All areas combined: mean 133 µg/g; median 61 µg/g, geometric mean 65 µg/g Residential areas: mean 210 µg/g; geometric mean 85 µg/g Open space land use: mean 71 µg/g; geometric mean 42 µg/g	Predicted BLL: IEUBK model. Overall BLL estimated to be 2.0 µg/dL, ranging from 1.3 to 16.8 µg/dL. Approximately 8.8% of the estimated BLL were above 5 µg/dL, and 2.3% above 10 µg/dL.	(Laidlaw *et al.*, 2017)
Residential soils, Metropolitan Melbourne	N=250, sample depth 0-2 cm	Residential soil lead: 193 µg/g (mean), 110 µg/g (median), 108 µg/g (geometric mean), 8 -3341 µg/g (range)	Predicted BLL: IEUBK model BLL: 2.9 µg/dL (mean), 2.3 µg/dl (median), 2.5 µg/dL (geomean), 1.3 to 22.5 µg/dL (range)	(Laidlaw *et al.*, 2018)
Residential soils near Superfund site	N=34 composite samples BLL, N= 70 children (ages 1-11 years) from 34 different residences sampled	Geometric mean: 16.9 µg/g, range: 5.39 to 59 µg/g.	Measured BLL. All BLL were less than 5 µg/dL	(Loh *et al.*, 2016)
Residential soil, New Orleans, Louisiana	N=5,467 surface soil samples (0-2.5 cm depth) stratified by census tracts BLL data collected by the Louisiana Childhood Lead Poisoning Prevention Program before and after Hurricane Katrina in 2005 (a major weather event that altered lead deposition in the city).	Soil lead: 6 to > 1,600 µg/g Areas divided into high lead (> 100 µg/g) and low lead (< 100 µg/g) areas	Measured BLL. The proportion of BLL greater or equal to 5 µg/dL was compared pre- and post Hurricane Katrina: High-lead group (pre-Katrina): 58.5% were > 5 µg/dL, Low-lead group (pre-Katrina): 24.8% > 5 µg/dL High-lead group (post-Katrina): 29.6%> 5 µg/dL. Low-lead group (post-Katrina) 7.5% > 5 µg/dL.	(Mielke *et al.*, 2014)
Urban soil samples, New Orleans, Louisiana	N=5,467 surface soil samples (0 to 2 or 3 cm depth)	High Lead (> 100 µg/g), median 366 µg/g, range 2.5 to 52,798 µg/g. Low Lead (< 100 µg/g) median 44 µg/g, range 2.5 to 10,184 µg/g	Measured BLL. High lead areas: Pre-Katrina median BLL: 5.6 µg/dL Post-Katrina median BLL: 3.0 µg/dL Low lead areas: Pre-Katrina median BLL: 3.0 µg/dL Post-Katrina median BLL 3.0 µg/dL	(Mielke *et al.*, 2017)
Residential soils, Indianapolis, Indiana in proximity to Avanti Superfund Site	Soil. N=266 samples, 0-5 cm. BLL: data for 1999-2008 evaluated. N=12,431 Children (ages 0 – 5 years, with continuous BLL data)	Soil: WESCO community, 259 µg/g (mean), range: < 50 µg/g (min) to 1,635 µg/g (max).	Measured BLL (all children): Marion County (n=12,431), average 2.76 µg/dL, geometric mean 1.81 µg/dL. WESCO neighbourhood (N=883), average 4.28 µg/dL, geometric mean 2.9 ZIP Code 46222 (includes WESCO, n=1,664), average 3.45 µg/dL, geometric mean 2.90 µg/dL	(Morrison *et al.*, 2013)

Table 5-6	Summary of Identified Studies Examining Soil Lead Concentrations and Predicted or Measured Blood Lead Levels			
Location	**Sample Characteristics**	**Soil Results**	**BLL**	**Reference**
Residential areas, France	N=315 soil samples BLL N=484 children (6 months to 6 years)	Soil: geometric mean 25 µg/g, range < 1 to 3,075 µg/g	Measured BLL. BLL geometric mean 1.4 µg/dL, range 0.26 to 30.8 µg/dL	(Oulhote *et al.,* 2013)
Urban lead concentration near primitive e-waste recycling facility, Montevideo, Uruguay	N=40 samples N=69 children and adolescents	Soil lead: mean 7,103 µg/g, range 650 to 19,000 µg/g	Measured BLL. First measurement: 0.3 to 28.4 µg/dL, mean 9.19 µg/dL, BLL second measurement (within 1-year), mean 5.86 µg/dL, range 0 to 19 µg/dL	(Pascale *et al.,* 2016)
Playground soils, Beijing, China	N=71, sample depth 10 cm	Soil lead: mean 36.2 µg/g, range 7.80 to 326 µg/g	Predicted BLL: IEUBK model and ALM used. BLL average 0.64 µg/dL, range 0.12 to 33.6 µg/dL.	(Peng *et al.,* 2019)
Residential soils near former smelter, Bunker Hill, Idaho	Data from several communities evaluated retrospectively Kellogg, N=118 children, ages 1-9yr) Page (N=15, ages 1-9 yr) Pinehurst (N=117, ages 1-9 yr)	Kellogg. Geometric mean: 435 µg/g. Page. Geometric mean: 287 µg/g Pinehurst: Geometric mean: 369 Soil (geometric mean) 287 µg/g	Predicted BLL: IEUBK model used. Kellogg: BLL (geometric mean) 6.3 µg/dL Page: BLL (geometric mean) 5.2 µg/dL Pinehurst: BLL (geometric mean) 3.7 µg/dL	(von Lindern *et al.,* 2016)
Residential soils, New Orleans, Louisiana	n=5,467, sample depth 0-2.5 cm, stratified by census tract BLL data for n-55,551 children (mean age 30.22 months, range 6-72 months) from 280 different census tracts between 2000-2005	Mean 249.42 µg/g, range 6.2 to 1789 µg/g	Measured BLL. BLL mean 5.68 µg/dL, range 0 to 117 µg/dL	(Zahran *et al.,* 2011)

5.2.2.1 Common Features of Lead in Urban Environments

While some studies were identified that examined soil lead concentrations related to specific point sources (Table C-2 of Appendix C), several other studies of urban areas in various locations in Canada, the United States, Australia, and Europe were identified (Table C-1 of Appendix C). The discussions of studies of lead in urban areas were primarily focused on the potential historical impacts of lead in these areas.

In the available studies of urban areas, the city centre, city core, or metropolitan areas typically presented the highest soil lead concentrations. The majority of the studies involved sampling depths of less than 5 cm, and thus are representative of soils that people may be exposed to during normal daily activities. Lead contamination was attributable to past emissions from historical industrial and transportation related sources (leaded fuels, mechanical parts), coal burning, and older housing with leaded paint (ATSDR 2019; Brown *et al*., 2008, Massas *et al*., 2010; Laidlaw *et al*., 2018; Mielke *et al*., 2014; Mielke *et al*., 2017; Rasmussen *et al*., 2001). Residential soils were reported to be more strongly associated with BLL than soils from foundations, busy streets, or open spaces (Zahran *et al*., 2013a). Higher lead concentrations in soils have been identified in soils collected near major traffic thoroughfares and in areas with exterior lead paint in various cities, including Sydney (Laidlaw *et al*., 2017) and Melbourne, Australia (Laidlaw *et al*., 2018).

In general, playground and sports field soils in various areas of China, Europe, and Mexico in the studies reviewed were found to have median lead concentrations less than 110 µg/g, with most median concentrations being below 70 µg/g (De Miguel *et al*., 2007; Glorennec *et al*., 2012, Gonzalez-Grijalva *et al*., 2019; Massas *et al*., 2010; Peng *et al*., 2019; Piekut *et al*., 2019). Playground soils may have been impacted by the addition or replacement of aggregate, or other fill material over time, as was noted in the study of Spanish playgrounds by De Miguel *et al*., (2007). Similarly, it is possible that garden soils are amended or replaced over time. As a result, there may be some uncertainty in directly comparing playground or garden soils from one area to another.

5.2.2.2 Relationships between Soil Lead Concentrations and BLLs in Urban Environments

In several studies, the potential influence of historically deposited lead in soil on contemporary human exposure was examined. An investigation of airborne particulate composition in El Paso, Texas concluded that lead contaminated soil resulting from historical deposition from anthropogenic sources such as leaded gasoline and industrial emissions is a long-term reservoir of lead that can be re-suspended into airborne particulate (Pingitore *et al*., 2009). A study of lead contamination in proximity to the Avanti Superfund site in Indianapolis, Indiana by Morrison *et al*. (2013) also found evidence that previous lead emissions deposited in un-remediated areas may be re-suspended and serve as a current exposure source. In addition to soil samples (n=266) from residences at varying distances from the Superfund site, dust samples were collected from furnace filters from a subset of homes (n=12). Blood lead levels in children ages 0-5 years were also evaluated. Although no direct relationship between soil lead concentrations and children's BLLs were identified in relation to a spatial scale of 100 m, the authors concluded that the resuspension of impacted soils was occurring based on the observed indoor lead concentrations. Approximately 60% of the variation in lead furnace dust concentrations between the samples were accounted for by soil lead concentrations on those same properties. Although several areas within Indianapolis were identified as having older (pre-1960) housing, no statistically significant relationship between housing age and BLLs was identified (Morrison *et al*., 2013).

Zahran *et al*. (2013b) investigated the relationship between BLLs and soil sample locations, including soil samples collected within 1 m of busy streets, residential streets, and home foundations, as well as in open spaces (away from roads, buildings – such as large residential lots or parks). Results indicated that soils collected within 1 m of residential streets most reliably predicted children's BLLs. Regression decomposition results showed that residential street soils accounted for 39.7% of between-neighbourhood explained variation in BLLs, followed by busy street soils (21.97%), open space soils (20.25%), and soils around the foundation of homes (18.71%).

Seasonal variability in BLLs have been reported in association with soil lead re-suspension, open windows, and direct contact. Blood lead data analysis for children less than 6 years of age in suburban and rural areas adjacent to, and including, Flint Michigan were analyzed by Laidlaw *et al*. (2016) for the years between 2010 and 2015 (note: the water supply change which resulted in the well documented elevated concentrations of lead in drinking water was made in April 2014). Between 2010 and 2013, BLLs were consistently higher in Flint relative to the State of Michigan as a whole and Genessee County (of which it is part) during the third quarter of the year (*e.g*., the months of July, August and September), with approximately 3.6% of measured BLLs being greater than or equal to 5 µg/dL. During the third quarter of 2014 (the summer immediately following the switch of the drinking water source), the percentage of children with a BLL greater than or equal to 5 µg/dL doubled to 7%. As part of this study, soil data collected in Flint between 2011 and 2015 (n=248) as part of a food survey were included in the analysis. Air quality data for Flint was not available for lead. Laidlaw *et al*. (2016) identified that the soil lead concentrations within the metropolitan centre were higher than soils along the outskirts, which is typical of other urban areas with historical lead deposition from gasoline, paint, and industrial emissions. A strong overlap was also identified in the areas with elevated soil lead, and the parts of the distribution network within Flint that were found to have increased lead concentrations in drinking water. Laidlaw *et al*. (2016) concluded that elevated BLLs with clear seasonal variability were evident in the Flint area before the contamination event that arose as a result of the change in water supply for part of the City. The data suggest that seasonal resuspension of lead was an important exposure source, that combined with lead leaching from the water pipes in warmer weather, contributed to increased in BLLs in the warmer months. The potential influence of the warmer weather resulting in more time spent outdoors and greater opportunity for exposure to lead in soils was not addressed in this study. Once the water supply change issue was identified, much attention was focused on that, with less attention on the patterns already evident in the BLL data. As a result, Laidlaw *et al*. (2016) emphasize that consideration of lead in surface soil, as well as drinking water, should be considered together with respect to mitigation measures.

Zartarian *et al*. (2017) completed multi-media modelling of lead exposure for children ages 0-7 years utilizing a probabilistic approach with the US EPA SHEDS multi-media model combined with the IEUBK model. Exposure from soil, drinking water, dust, food, and air were evaluated with the intent to determine lead concentrations in drinking water that would result in a BLL below 5 µg/dL. The soil and dust pathways were determined to be the most dominant routes of exposure to lead in US children between the ages of 0 and 2 years, followed by the ingestion of drinking water. The model was found to be especially sensitive to soil and dust ingestion rates for children between the ages of 0 and 7 years old. The modelling concluded that daily exposure to drinking water containing less than approximately 2.5 µg/L lead is associated with

97.5% of BLLs being below 5 µg/dL, with all other exposure pathways remaining constant in the model (Zartarian *et al*. 2017).

Oulhote *et al*. (2013) concluded that lead concentrations in exterior soils, as well as tap water and floor dust, were significantly associated with BLLs and represented primary sources of exposure. However, when the potential impact of lowering lead guidelines or intervention levels in each of these media were evaluated, only potential reductions in tap water concentrations and interior floor dusts remained statistically significant, suggesting that water and interior dust have a greater influence on BLLs.

Ren *et al*. (2006) found that lead in soil at concentrations of less than 500 µg/g resulted in BLLs of approximately 5 µg/dL in children living in urban areas in China. The study measured BLLs and soil lead at ten kindergartens in Shenyang, China where lead pollution resulted primarily from automobile exhaust and industrial emissions. Concentrations of lead in soil at kindergartens ranged from 53 to 350 µg/g, and BLLs in children aged 3 to 5 years ranged from approximately 1 to 5 µg/dL. The BLLs were lower in the younger children, with levels ranging from approximately 1 to 1.85 µg/dL in 3-year olds, 1 to 2.3 µg/dL in 4-year olds, and up to a maximum of 5 µg/dL in 5-year olds (Ren *et al*., 2006).

A blood lead screening study (Decou *et al*., 2001) was commissioned by the Regional Niagara Public Health Department in 2001 to determine exposure to, and potential health impacts of, lead in Port Colborne, Ontario, and specifically the Eastside Community in which elevated soil lead concentrations were identified (arithmetic mean of 203 µg/g and a maximum of 1,350 µg/g). In total, 1,065 individuals were screened, with approximately one-third of all participants from the Eastside Community. The geometric mean BLL for the Eastside Community was reported as 2 µg/dL. While BLLs for children were compared to soil data for collection sites on each particular residential property, no statistical relationship was apparent between the two variables. Based on the results of the blood lead screening program, average Eastside Community BLLs were considered to be low and similar to those observed in the rest of Port Colborne, as well as other similar Ontario communities. The researchers concluded that children and pregnant women in the Eastside Community were not at an increased risk of lead exposure as compared to other communities in Ontario, despite the localized elevated soil lead concentrations (Decou *et al*., 2001).

In a study conducted by Etchevers *et al*. (2015), the authors investigated the contribution of environmental sources of lead to BLLs in children in France. BLLs were measured in children (n=484; age 6 months to 6 years) in a cross-sectional survey in 2008-2009, and lead concentrations were measured in different environmental samples (water, soils, household settled dusts, paints, cosmetics, and traditional cookware) collected within and/or outside (*e.g*., backyard) the children's residential dwelling. Two types of modelling were performed, including a multivariate generalized additive model on the geometric mean, and a regression model on the 10th, 25th, 50th, 75th and 90th percentile of BLLs. The geometric mean BLL was 1.38 µg/dL (95% confidence interval (CI): 1.27-1.49 µg/dL) and the 90th percentile was 2.57 µg/dL (CI: 2.42-2.95 µg/dL). Although household and common area dust, tap water, interior paint, ceramic cookware, traditional cosmetics, playground soil and dust, and environmental tobacco smoke were associated with the geometric mean of BLLs, household dust and tap water made the largest contributions to both the geometric mean and the 90th percentile of BLLs. Lead concentrations in tap water at >5 µg/L were positively correlated with the geometric mean, 75th and 90th percentiles of BLLs in children drinking tap water. Furthermore, the concentration of lead in dust was positively correlated with all percentiles of BLLs even at low concentrations. (Etchevers *et al*., 2015). These results are consistent with Rasmussen *et al*. (2001) which concluded that only about 2-4% of total daily lead exposure is related to outdoor soils based on a study in Ottawa, Ontario. Dust concentrations in Ottawa were found to be approximately 5-times higher than outdoor soil concentrations among the 50 residences included in the study (Rasmussen *et al*. 2001).

Bradham *et al*. (2017) examined the relationship between total or bioaccessible lead concentrations in soil and children BLLs in an urban neighbourhood in Philadelphia, Pennsylvania with a history of soil lead contamination. The bioaccessible concentration was determined *via in vitro* bioaccessibility assay and represents the fraction of the total soil lead concentration that is released from ingested soil and available for absorption. BLLs were measured in 49 children (1 to 7 years old) and soil samples were collected from the 38 homes associated with these children (some homes had more than one child). Hierarchical models were used to compare relationships between total or bioaccessible lead concentrations in soil and children BLLs. Total soil lead concentrations ranged from 58 to 2,821 µg/g and bioaccessible lead concentrations ranged from 47 to 2,567 µg/g, while children's BLLs ranged from 0.3 to 9.8 µg/dL. As shown in Figure 5-6, a significant positive relationship was found between BLLs in children and soil lead levels (both total and bioaccessible). Furthermore, hierarchical modelling showed that both total and bioaccessible lead concentrations in soil were significant predictors of BLL at the 99% confidence interval (p=0.0036 and p=0.0014, respectively). The hierarchical BLL model based on total soil lead concentrations had an intercept of 1.3 µg/dL BLL and a slope of 1.3 µg/dL BLL per 1,000 µg/g increase in total lead concentrations, while the fitted hierarchical model with bioaccessible lead concentrations had an intercept of 1.2 µg/dL BLL and a slope of 1.5 µg/dL BLL per 1,000 µg/g increase of bioaccessible lead in soil. These results were consistent with past reports of BLL increases ranging between 0.6 to 6.8 µg/dL for every 1,000 µg/g increase in soil lead (Duggan, 1980; Lanphear *et al*., 1998; US EPA, 1983). However, children's age did not contribute significantly to the prediction of BLLs. Therefore, based on the findings of this study, the authors suggest that for every 1,000 µg/g increase in soil lead, there is an increase of 1.3 to 1.5 µg/dL in children BLLs.

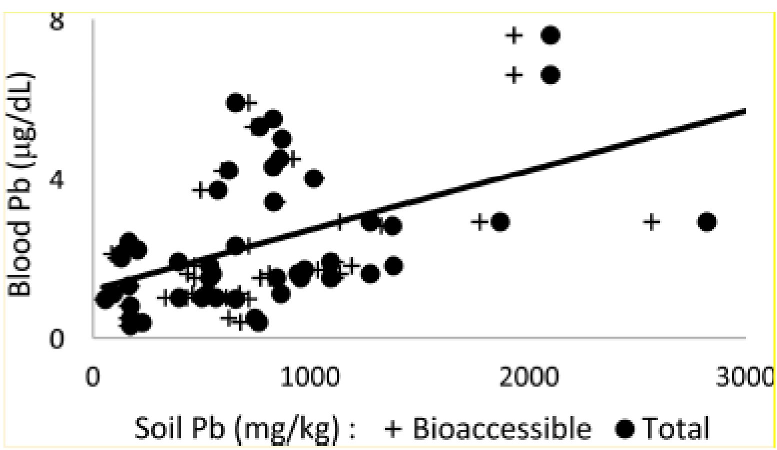


Figure 5-6 Relationship between total or bioaccessible soil lead and BLLs in Children (Bradham *et al*., 2017).

The occurrence of hurricane Katrina in 2005 and its impact on the City of New Orleans allowed for an evaluation of the effects of the resulting soil re-distribution and the reconstruction of housing within inner-city areas on BLLs. Several studies of the relationship between environmental lead exposure, BLLs, and human health have been completed within the New

Orleans area since 2001. The natural intervention of Hurricane Katrina in 2005 resulted in mass flooding and the deposition of new soils and sediment transported *via* floodwaters from other areas, a circumstance that allowed for the examination of soil lead concentrations and BLLs before and after the incident within the population (Mielke *et al*., 2019). In addition, housing in older communities that were known to be affected by lead-based paint were demolished after the flooding and reconstructed. The median soil lead concentration before the hurricane in New Orleans was 289 µg/g, and the median BLL was 5 µg/dL for children less than 6 years of age. A follow-up study and comparison with pre-hurricane data was completed by Mielke *et al*. (2017) in 2015, 10 years after the event. The median soil lead concentration within the City was reduced to 143 µg/g as a result of soils with low lead concentrations from the coastal environment having been carried into these areas by floodwaters. As a result of this change in soil lead concentrations, as well as the overall improvement in residential dust lead levels as a result of the removal of lead-paint impacted materials, the median BLL in children under 6 years of age dropped to 1.9 µg/dL (Mielke *et al*., 2017) (Figure 5-7).

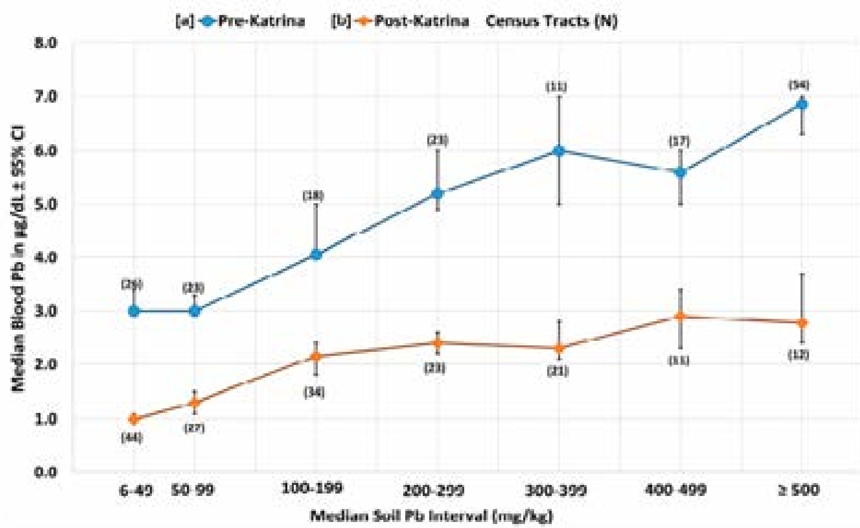


Figure 5-7 Pre-Katrina and Post-Katrina soil lead and BLL changes in New Orleans Parish (164 census tracts) and St. Bernard Parish (8 census tracts) (Mielke *et al*., 2017).

In a related study, the relationship between BLLs in children and soil lead concentrations was further evaluated using data collected pre- and post-Hurricane Katrina (Mielke *et al*., 2013; Mielke *et al*., 2014). A large soil lead database (n=5,467) and BLL databases (n=55,551 pre-Katrina and 7,384 post-Katrina) were used. New Orleans was divided into high (≥100 µg/g) and low (<100 µg/g) soil lead communities and the proportion of BLLs in children at ≥5 µg/dL was compared pre- and post- hurricane. In general, BLLs above 5 µg/dL occurred within the inner-city areas, with lower BLLs occurring in the outer-city areas. These measurements correlated with differences in soil lead concentrations between these areas. Pre-hurricane, the percentage of BLLs in children at ≥5 µg/dL were 58.5% and 24.8% for the high and low soil lead communities, respectively. These values decreased to 29.6% and 7.5%, respectively, post-hurricane. These data suggest that reductions in soil lead and dust as a result of the deposition of non-impacted soils after the flood and the construction of new housing resulted in a substantial decline in BLLs in New Orleans, particularly in the inner-city.

A number of additional studies evaluated relationships between soil lead concentrations and BLLs of children in New Orleans using the universal BLL screening dataset (n=55,551) from 2000-2005 spatially coupled with a soil lead dataset (n=5,467) completed in 2000. Mielke *et al*. (2007) evaluated empirical associations between soil lead concentrations and BLLs and determined that a consistent curvilinear association occurred annually between soil lead and BLLs with robust significance ($p<1 \times 10^{-23}$). Below soil lead concentrations of 100 µg/g, the BLL response was steep (1.4 µg/dL per 100 µg/g), while above 300 µg/g soil lead, the BLL response was more gradual (0.32 µg/dL per 100 µg/g). A scatter plot of the pooled soil lead and BLL data for 2000-2005 (n=1,680) is shown in Figure 5-8. The derived model of the association between median soil lead and median BLL was described as: $BLL=2.038+0.172 \times (\text{soil lead})^{0.5}$ ($R^2=0.528$; $p=1.0 \times 10^{-211}$).

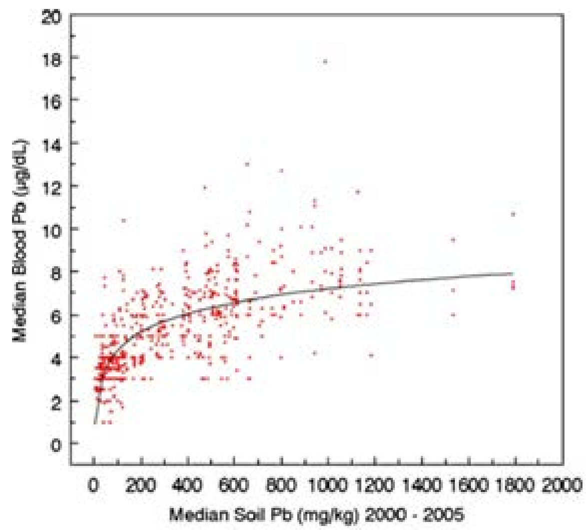


Figure 5-8 Relationship between soil lead and BLL data for children in New Orleans for 2000-2005 (Mielke *et al*., 2007).

To downscale, this analysis to the individual child level, Zahran *et al*. (2011) investigated the curvilinear associations between soil lead concentrations, age of children (6 to 72 months), and BLLs. The authors utilized random effects generalized least squares modelling to predict BLLs in children, whereby age and soil lead variables were square root transformed. Across all models tested, both the square root of age (*i.e.*, $age^{0.5}$) and the square root of exposure level (*i.e.*, soil $lead^{0.5}$) were positively and significantly associated with BLLs, when adjusting for year (date) of BLL observation. For the selected model, a unit change in the square root of age increased BLLs in children by 0.401 ($p \le 0.001$), and a unit increase in the square root of soil lead increased child BLL by 0.214 ($p \le 0.001$). Furthermore, a unit change in $age^{0.5}$ increased the odds of children's BLLs exceeding 10 µg/dL by a multiplicative factor of 1.23 (95% CI: 1.21 to 1.25), and a unit (µg/g) addition of soil lead increased the odds of children's BLLs exceeding 10 µg/dL by a factor of 1.13 (95% CI 1.12 to 1.14). Overall, the authors concluded that childhood BLLs are represented by a curvilinear function of both age and soil lead concentration, with age having a greater influence at lower BLLs and soil lead concentration at higher BLLs. Figure 5-9 shows the predicted BLL per unit change in observed soil lead concentration when fixing age at the sample mean of 30.22 months.

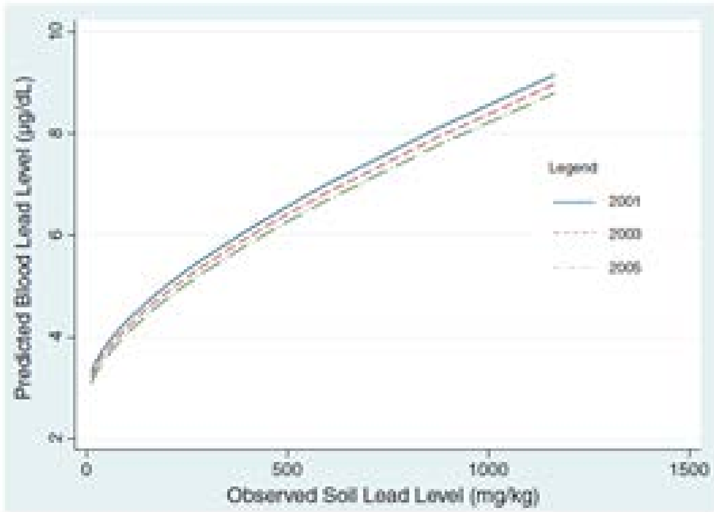


Figure 5-9 Relationship between soil lead and BLL data for children in New Orleans for 2000-2005 (Zaharan *et al*., 2011).

A similar curvilinear relationship was identified when the correlation between blood lead screening values for children in Syracuse, NY and soil lead concentrations was investigated by Johnson and Bretsch (2002). A total of 12,228 blood samples were collected from children (age 0-6 years) from 194 different locations within the city limits for Syracuse, NY, and soil samples were collected in a 600m x 600m tessellation grid covering the city. The geometric mean soil lead concentration in the study was 80 µg/g (95% of samples had a concentration range of 20 to 800 µg/g) and 27.6% of children sampled (n=3,375) had BLLs greater than 10 µg/dL. Although, no meaningful relationship was found between soil lead and BLLs when using the 600m x 600m grid, a strong relationship was found when soil lead data were aggregated at a large geographic scale (~3 km^2), and each spatial unit contained at least nine (9) soil lead measurements. Logarithmic modelling showed a coefficient of determination (R^2) >0.65 for regression of geometric mean BLLs against median soil lead measurements. The logarithmic regression equation for the all-season data was: BLL (µg/dL)= 1.7592 Ln[soil lead concentration(ppm)] − 2.449 (R^2=0.706) and for the summer data was: BLL (µg/dL)= 2.0973 Ln[soil lead concentration(ppm)]− 3.6026 (R^2=0.6684). In another study evaluating the relationship between soil lead levels and BLLs in Syracuse, the BLL of children (age 0-6 years) were stratified by census tract and paired with soil lead measurements (n=175) (Mielke *et al*., 1999). Similar to the findings of Johnson and Bretsch (2002), Mielke *et al*. (1999) found a significant association between median BLL and soil lead levels and the relationship was quantified by the following model: BLL =3.06 + 0.33(soil lead concentration)$^{0.5}$ (R^2=0.69; p=3.5x10^{-22}). Overall, the soil lead/blood lead relationship was very similar between the two studies (Figure 5-10).

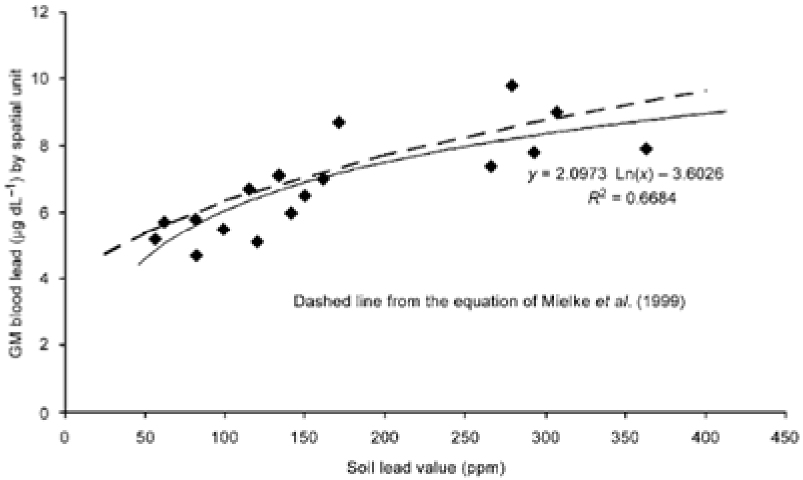


Figure 5-10 Relationship between soil lead and BLLs in children in Syracuse, NY (Johnson and Bretsch, 2002).

Overall, models describing the association between soil lead concentrations and BLLs in children have been reported throughout the literature and these models have shown significant and strong associations between the two variables on a case-by-case basis. However, it is important to note that models varied across studies, and other factors including seasonal variability and child age, can have a significant impact on lead exposure in children. Furthermore, the results described by Johnson and Bretsch (2002) also emphasize the importance of using large blood lead and soil lead monitoring data sets when determining associations between these variables.

To demonstrate the variability in the soil lead vs BLL relationships estimated using empirical data, correlations identified by Bradham *et al*. (2017), Mielke *et al*. (2017) (pre- and post-hurricane Katrina), and Mielke *et al*. (2007) were plotted together with the relationship predicted by the IEUBK model (Figure 5-11). This comparison indicates that there is a large degree of uncertainty in utilizing empirical results and modelled relationships to predict BLLs in children. This comparison also demonstrates that the slope predicted using the IEUBK model is greater than those derived using empirical data, however, at soil lead concentrations below 100 µg/g the IEUBK model predicted lower BLLs than the empirical relationships. At relatively low soil lead concentrations, the curvilinear relationships identified by Mielke *et al*. (2007), Johnson and Bretsch (2002), Zahran *et al*. (2011) may be the most applicable models for most Winnipeg neighbourhoods. These relationships demonstrate that BLLs increase at a sharper rate at soil lead concentrations below 100 µg/g, followed by a more gradual increase around 300 µg/g. Use of these models would predict geometric mean BLLs of greater than 2 µg/dL at concentrations below 100 µg/g, indicating potential concerns for several Winnipeg neighbourhoods, however, it is unknown if non soil-related exposures in the communities that these relationships were based on are similar to those in Winnipeg. As a result, there is uncertainty in the application of the empirical results to predict BLLs in Winnipeg neighbourhoods.

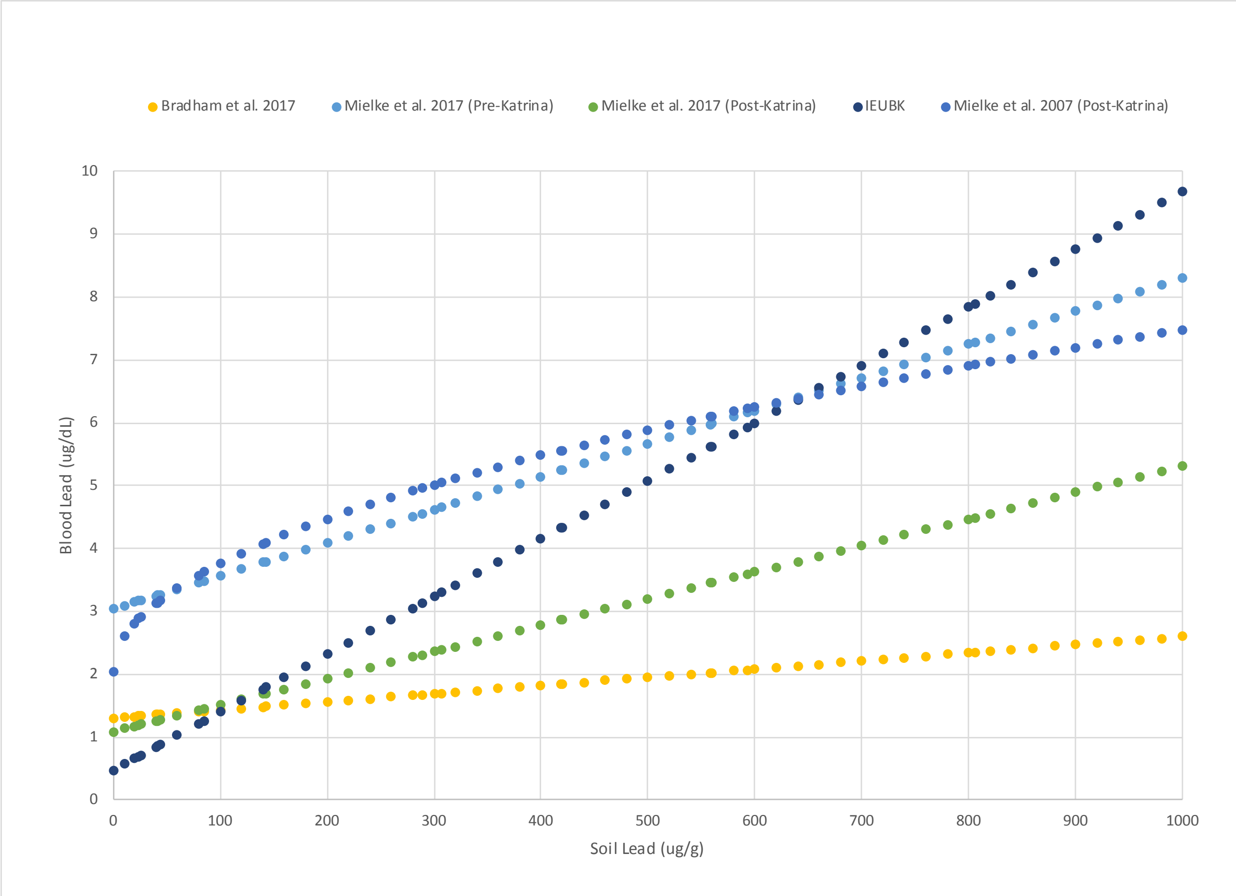


Figure 5-11 Comparison of literature-based correlations of soil lead and BLLs with the IEUBK-predicted correlation

5.2.2.3 Comparison of Central Estimates of Soil Lead in Literature to Winnipeg Neighbourhoods of Potential Concern

Soil lead concentrations in Winnipeg neighbourhoods identified as being of potential concern were compared to concentrations identified in the literature for other urban areas. Priority was given to those studies that focused on urban areas where there were no dominant point sources of emissions and soil lead contamination was likely attributed to factors such as historical vehicle emissions and leaded paint (Table C-1). Median soil concentrations were selected over means where possible as this statistic is less influenced by outliers and provides a central estimate within the data distribution (*i.e.*, the 50th percentile) and allowed for the use of a consistent measurement across studies rather than an average which may have been reported as an arithmetic or geometric mean. To facilitate a direct comparison with the available data for the neighbourhoods of interest within Winnipeg, preference was given to data that included residential areas, gardens, open spaces, schools, playgrounds, parks and other public lands (*e.g.*, near public buildings), and areas near roadways and boulevards. Additional details regarding these studies is provided in Appendix C.

Median soil concentrations and other descriptive statistics for the Winnipeg neighbourhoods of potential concern are presented in Table 5-7 using the results of the soil investigations conducted by the Province in 2007/2008 (Manitoba Conservation, 2010) and the University of

Manitoba (2017). Table 5-8 presents the results of the 2018 Provincial investigation (Manitoba Sustainable Development, 2019) and the University of Manitoba (2017) investigation. As several samples from the 2018 Provincial investigation were intended to be co-located with the sampling sites from the 2007/2008 investigation, these two data sets were not combined. Separating these data also allowed for consideration of the influence of the different sampling depths utilized in each of these studies (*i.e.*, ≤5 cm for the 2007/2008 data set and 0-7.5 cm for the 2018 data set).

The median soil concentrations derived using the 2007/2008 Provincial data and the University of Manitoba (2017) data from Table 5-7 are presented visually in Figure 5-12 as coloured horizontal lines that are contrasted with the reported medians/central estimates for other urban areas identified in the literature. In addition to this Figure, a summary table of studies completed after the year 2000 that included both soil lead measurements and either an estimation or measurement of BLL is provided in Table C-3 with the aim of providing additional context to the Winnipeg soil results.

Table 5-7 Summary Statistics for Winnipeg Neighbourhoods of Potential Concern (Manitoba Conservation, 2010; University of Manitoba, 2017)

Neighbourhood	Number of Samples	Arithmetic Mean	95% UCLM[a]	Median	Minimum	Maximum
Centennial	14	110	155	75.5	18	307
Daniel McIntyre	41	142	191	90	2	712
Glenelm/Chalmers	45	71.6	101	42	3	369
North Point Douglas	33	473	647	235	31	2,240
River/Osborne	10	60.4	119.5	39.5	17	204
Sargent Park	13	93.8	242	16.9	2.2	368
St. Boniface	197	87.8	94.0	42.5	4.86	1,630
West End	9	101	150	63	21	77.9
Weston	81	224	283	113	2.2	1,130
Wolseley/Minto	48	74.4	111	66	9	290

[a] Recommended value calculated by ProUCL.

Table 5-8 Summary Statistics for Winnipeg Neighbourhoods of Potential Concern (Manitoba Sustainable Development, 2019; University of Manitoba, 2017)

Neighbourhood	Number of Samples	Arithmetic Mean	95% UCLM[a]	Median	Minimum	Maximum
Centennial	4	13.5	61.3	39.0	36.1	59.8
Daniel McIntyre	4	67.1	130	54.9	22.7	136
Glenelm/Chalmers	19	61.0	77.3	47.7	14.2	141
North Point Douglas	27	189	279	99.1	15.6	885
River/Osborne	1	14.6	NC	14.6	14.6	14.6
Sargent Park	5	139	1,040	57.4	52.4	439
St. Boniface	177	88.6	92.9	42.5	4.86	1,630
West End	1	54.4	NC	54.4	54.4	54.4
Weston	35	174	203	180	30.2	446
Wolseley/Minto	21	38.5	46.4	33.5	11.3	105

[a] Recommended value calculated by ProUCL
NC Not calculated due to limited sample size.

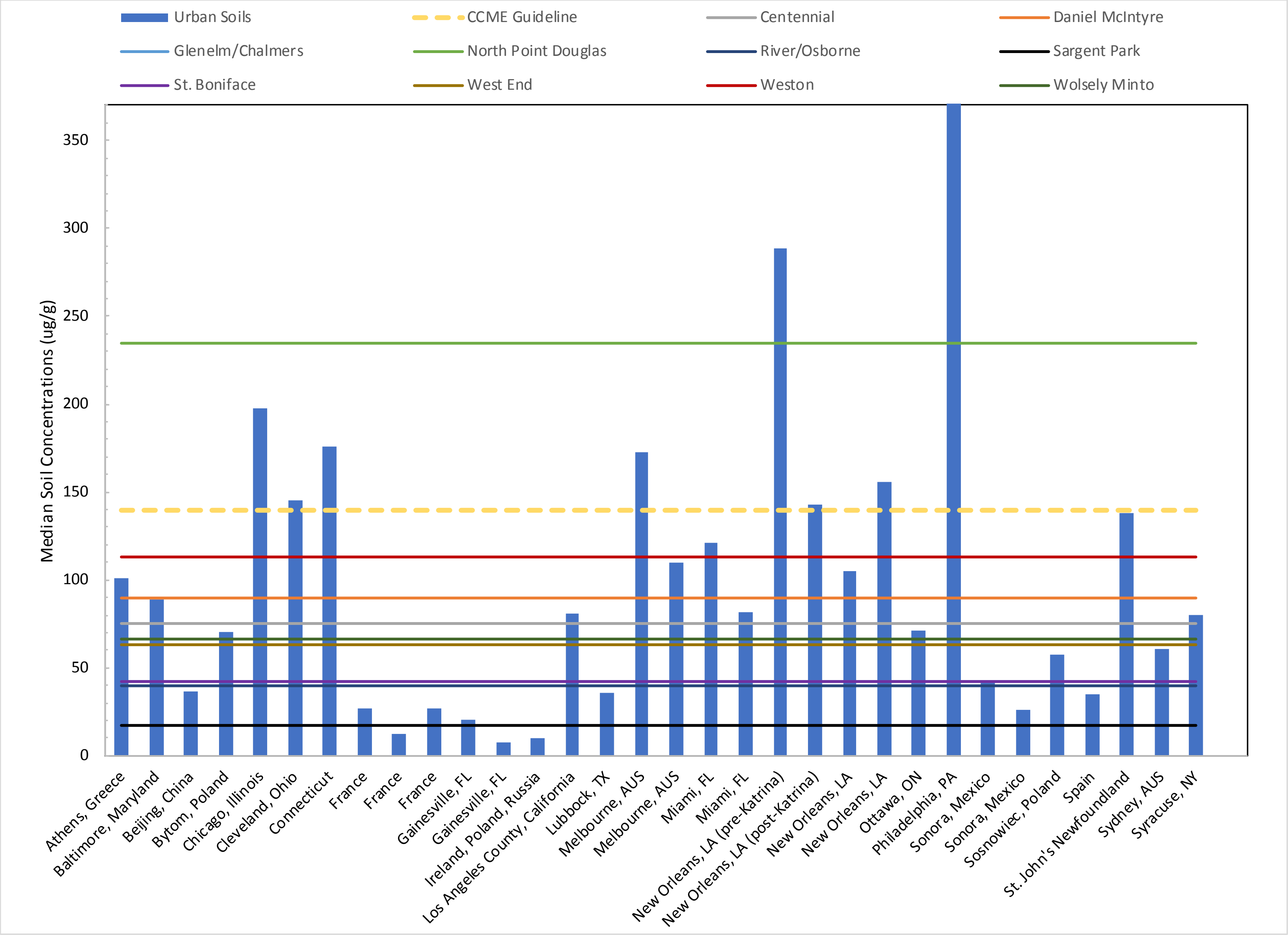


Figure 5-12 Comparison of Median Soil Lead Concentrations in Urban Areas with those for Neighbourhoods of Potential Concern in Winnipeg

5.2.2.4 Lead in Winnipeg Neighbourhoods

Median soil concentrations for the Winnipeg neighbourhoods of potential concern are presented as coloured horizontal lines within Figure 5-12, while medians for urban soils from studies identified within the literature are presented as vertical blue bars. This figure highlights the diversity in the soil lead medians within the available data for the City of Winnipeg and other international communities. While there is some 'clustering' of the medians for certain neighbourhoods (*e.g.*, St. Boniface and River/Osborne with approximate medians of 40 µg/g; Wolseley/Minto and West End with approximate medians of 65 µg/g), there are also clear differences for other neighbourhoods. The highest estimated median (North Point Douglas, 235 µg/g) is almost 14-times higher than the lowest median (Sargent Park, 16.9 µg/g). In addition, the median lead concentrations for Weston (113 µg/g), Daniel McIntyre (90 µg/g), and Centennial (74.3 µg/g) are distinct from each other, as well as the other medians for the Winnipeg neighbourhoods. The sections below provide a discussion of the findings for Winnipeg neighbourhoods of potential concern.

North Point Douglas

The median soil lead concentration for North Point Douglas (235 µg/g, green line) is higher than the CCME residential guideline of 140 µg/g (yellow dashed line). As noted in Table 5-7, the range of soil concentrations in this area was 31 to 2,240 µg/g, with an average concentration of 473 µg/g (based on 33 soil samples). The results presented in Figure 5-12 indicate that the North Point Douglas median (235 µg/g) is above most of the urban areas identified in the literature, including the median lead concentrations in Ottawa (71.1 µg/g) (Rasmussen *et al*., 2001) and St. John's Newfoundland (138 µg/g) (Bell *et al.*, 2010), as well as medians identified from studies of large US cities such as Baltimore, Chicago, Miami, Los Angeles and various other international locations.

The North Point Douglas median is within the range of the urban soil data for the City of New Orleans, Louisiana (median of 289 µg/g) collected before Hurricane Katrina redistributed soils in the area in 2005 (Mielke *et al*., 2017). The overall range in soil lead concentrations in pre-Katrina New Orleans (6.2 to 1,789 µg/g) (Zahran *et al*., 2011) is smaller in magnitude than the reported range for North Point Douglas. The geometric mean BLL for children age 0-6 years in New Orleans for the years 2000-2005 was 5 µg/dL (Mielke *et al*., 2017). Zahran *et al*. (2011) also reported that BLLs in the N=55,551 children examined in New Orleans between 2000-2005 ranged from non-detect to 117 µg/dL. The North Point Douglas median is higher than the median soil concentration in New Orleans after Hurricane Katrina (143 µg/g), where housing had been replaced after flooding and a new surface soil layer had covered the City. The geometric mean BLL was reduced to 1.9 µg/dL, 10 years after the storm event (Mielke *et al*., 2017).

Soil samples collected during the 2007/2008 Provincial investigation in North Point Douglas were from residential boulevards at similar sampling locations utilized in previous studies conducted during the 1980s. Manitoba Conservation (2010) noted that soil lead concentrations were influenced by vehicular emissions, as well as suspected emissions from nearby scrap yards, and that soil lead concentrations within North Point Douglas had generally decreased since the sampling was completed in 1988 (range 82 to 4,650 µg/g; median 535 µg/g). While the Province of Manitoba has not established a background level of lead in soil, the Ministry of the Environment, Conservation and Parks (MECP) of Ontario has identified a value of 120 µg/g as the typical background lead concentration in Ontario soils that have been influenced by anthropogenic activities. For North Point Douglas, more than 50% of the data for lead in soil is above the Ontario background level of 120 µg/g.

In the 2018 Provincial investigation, the soil samples collected for all locations, including North Point Douglas, were from a depth of 0-7.5 cm. This sampling depth is below what is considered to be representative of surface soils to which people may reasonably be exposed on a frequent and ongoing basis, as outlined in guidance developed for the risk assessment of lead of the US EPA Superfund program (US EPA, 2003). The median soil concentration for North Point Douglas from the 2019 study (99.1 µg/g; range 15.6 to 885 µg/g) is lower than that reported from the 2007-2008 sampling program. The differences in these results may potentially be attributed to the inconsistent sampling depths between the two studies, as well as the sampling dates relative to the phasing out of leaded fuels. Although samples from each study were collected from the same approximate locations on residential boulevards, there may be differences in the exact locations given the lack of geographical coordinate tracking during the 2007/2008 sampling. With respect to non-boulevard areas, only two schools in North Point Douglas and one corner of a ballpark were sampled. No sampling was conducted on private residences. As a result, it is unclear if the soil data set for North Point Douglas is representative of soil concentrations to which the most sensitive individuals (*e.g*. children under the age of 6 years) may be exposed on a frequent and prolonged basis.

The potential source(s) of soil lead contamination is not clear, but it is likely the result of a combination of factors. The neighbourhood is one of the oldest in Winnipeg (WRHA 2015c) and is transected by a railway and two major roadways (Main Street and the Disraeli Freeway). North Point Douglas lies within a larger area defined by the City of Winnipeg as the Point Douglas Community area (City of Winnipeg 2019a). The Winnipeg Regional Health Authority (WRHA) defines the Point Douglas area as including the neighbourhoods of: Burrows Central, Inkster-Faraday, Luxton, Mynarski, Robertson, St. Johns in the north portion, and the neighbourhoods of Dufferin, Dufferin Industrial, Lord Selkirk Park, North Point Douglas, South Point Douglas and William Whyte (WRHA, 2015c). The soil investigations conducted by the Province, as well as the current assessment, defined the neighbourhoods of North Point Douglas as the small geographical area of the wider Point Douglas area bordered by Main Street to the west, the Red River to the north, east and south. A discussion of the sociodemographic characteristics of the Point Douglas Area as a whole is provided in Section 5.2.2.3.

Limited information for the neighbourhood of South Point Douglas is available for comparison. Only three (3) soil samples for South Point Douglas were presented in Manitoba Conservation (2010), and two (2) in Manitoba Sustainable Development (2019). Only one data point is available for the adjacent neighbourhood directly west of Main Street, in the area known as Lord Selkirk Park (a soil concentration of 97.7 µg/g). No soil data are available for the nearby neighbourhoods of North End or William Whyte. Only two (2) samples are available from Manitoba Conservation (2010) for the adjacent neighbourhood of Dufferin, while 25 are available in the Manitoba (2019) report (although from a sampling depth of 0-7.5 cm in the latter). Additional information regarding this sampling data are provided in Section 2.1.3. Despite the Point Douglas Area as a whole being denoted as one of the older areas within the City (and thus likely heavily influenced by historical traffic, industrial emissions, and lead-based paint), there is a lack of overall sampling coverage that would allow for the complete delineation of soil lead concentrations.

Weston

The median soil lead concentration for the neighbourhood of Weston (113 µg/g) based on the 2007/2008 Provincial investigation is higher than the median for many other urban areas identified in the literature, but is lower than median concentration for North Point Douglas as well as the MECP anthropogenic background concentration of 120 µg/g. The range of lead concentrations in soil within this data set is from 2.2 to 1,130 µg/g. When the results of the 2018 Provincial investigation are considered, the median is higher at 180 µg/g, with a more limited range of values (minimum 30.2 to 446 µg/g). This variation could be due to slight differences in the locations of where samples were collected, or differences in the soil sampling depth.

Several studies have been completed within the Weston area since the late 1970s following the identification of elevated BLLs in local workers and children. A combination of heavy traffic and industrial emissions were concluded to have impacted soils in this neighbourhood. Various soil and foliage studies were conducted, and remediation activities took place during the mid-1980s for several locations in this neighbourhood (see Section 2.2). Following the excavation of soils containing concentrations of lead greater than 2,600 µg/g (the soil quality guideline at the time), soils containing levels of lead below 200 µg/g were added to these sites. While soils in additional areas may have been disturbed and replaced through landscaping and construction activities over time, no other remediation activities in the area are noted within the available reports (Section 2.2).

All of the samples collected within the Weston neighbourhood as reported in the Provincial investigations (2007/2008 and 2018) were collected from either the Weston Elementary school, playgrounds, or sports fields, and are thus clustered in these areas. All of the samples reported in 2010 were collected from soils at a depth of less than 5 cm, whereas the samples reported in 2019 were from 0-7.5 cm. No residential properties or boulevards from residential areas were sampled as part of either of these investigations, and there is an overall limited degree of spatial coverage of sampling data for this neighbourhood. As a result, there is uncertainty regarding the applicability of the available data to characterize potential exposure to children in this neighbourhood, particularly those children who are within the highest risk group for lead (children under the age of 6 years) who are not yet attending school. The potential contributions from one or more secondary smelters, and possibly other sources in this neighbourhood, were highlighted previously in this report (Sections 2.1.1, 2.2.9, and 3.2.1.1), which further emphasizes the potential need for supplemental soil sampling and/or other methods to characterize lead exposure in this neighbourhood.

Using the 2007/2008 data, the median soil concentration of 113 µg/g is somewhat comparable to the median lead concentration in the City of St. John's Newfoundland (148 µg/g) reported by Bell *et al*. (2010). The highest soil lead concentrations in St. John's were identified in neighbourhoods and properties with older housing (pre-1950s) where the previous combustion of coal for heat and transportation, leaded gasoline, and the use of lead-based paint were all identified as possible sources. Over half of the 1,231 samples collected in this study were found to have lead concentrations greater than 140 µg/g, with 10% of the samples containing more than 1,000 µg/g of lead. As noted within the case study in Section 4.2.5.5, the IEUBK model was used to predict a geometric mean BLL of 6.5 µg/dL for children in St. John's. A follow-up biomonitoring study completed years later determined that the geometric mean BLL in children less than 7 years of age was 1.12 µg/dL, suggesting that the IEUBK model overpredicted BLLs for the community.

The median soil concentration for Weston is also similar to the median for residential soil samples collected from the Metropolitan area of Melbourne, Australia (110 µg/g) by Laidlaw *et al*. (2018). Lead concentrations were found to be elevated in the central and western areas of the city, and 20% of the 250 samples contained lead at concentrations above the Australian guideline of 300 µg/g. IEUBK modelling was completed to estimate the BLL of a hypothetical 24-month old at each location. The model estimated a geometric mean BLL of 2.5 µg/dL, with values ranging from 1.2 to 22.5 µg/dL (Laidlaw *et al*. 2018).

The data collected by Petersen *et al*. (2006) in Cleveland Ohio included 50 soil samples, where lead concentrations were found to range from 19 to 811 µg/g, with a median of 145.5 µg/g. The sampling sites in this study included public areas and green spaces within dense urban neighbourhoods that included playground areas. Concentrations of lead were found to exceed the Ohio soil quality guideline of 400 µg/g, with potential sources noted as including urban brownfield sites with heavy metal burdens and historical airborne lead deposition from various facilities, which is noted to be typical for older industrial cities (Petersen *et al*., 2006). Blood lead monitoring was not conducted as part of the Petersen *et al*. (2006) study.

The Weston neighbourhood, along with the areas of Brooklands, Burrows-Keewatin, Shaughnessy Park, Inkster Gardens, and Tyndall Park, are all considered to be part of the Inkster Community area (WRHA, 2015b). Soil sampling data are available for Brooklands, Shaughnessy Park, Shaughnessy Heights, and Tyndall Park. The data available from the 2007/2008 and 2018 Provincial investigations indicate that the majority of soil samples collected in these four areas contain concentrations of lead that are below the CCME soil quality guideline of 140 µg/g, with only one sample from Shaughnessy Park exceeding the guideline (with a concentration of 176 µg/g). However, no information is available from the Provincial investigations for Inkster Gardens or Burrows Keewatin. The latter area is located directly north of the Weston railyard and Weston Shops area. This represents a data gap, given the presence of a railway and industrial emission sources in the area. The lack of samples in Inkster Gardens is less of concern, as this neighbourhood is located further north and away from the City core.

Daniel McIntyre, Centennial, Sargent Park, Wolseley/Minto and West End

Daniel McIntyre is considered by the WRHA (2015a) to be part of the Downtown Community Area, specifically the west downtown. Other neighbourhoods in this area include Centennial, St. Matthews, Minto, Sargent Park, West End, and Wolseley (WRHA, 2015a). These data sets are discussed together as a result, where possible.

The median soil lead concentration for Daniel McIntyre (90 µg/g, orange line in Figure 5-12) stands apart from the other neighbourhoods such as Dufferin, Glenelm/Chalmers, River/Osborne, Sargent Park, St. Boniface, West End, and Wolseley/Minto, all of which have median soil lead concentrations less than 70 µg/g. The Daniel McIntyre median of 90 µg/g is within the upper portion of the range of medians for urban areas reported in the literature. Soil lead concentrations, based on the 2007/2008 Provincial study, range from 2 to 712 µg/g within this neighbourhood. Using the 2018 Provincial data, the median for Daniel McIntyre is lower at 54.8 µg/g, and the range is smaller (22.7 to 136 µg/g). This lower median is within the range of medians presented in Figure 5-12 for various urban areas, and is within the range of the medians and means of some studies presented in Table 5-6 where soil lead concentrations and BLLs are compared. In residential areas of Melbourne, Australia, Laidlaw *et al*. (2018) determined that the median soil lead concentrations (mean 193 µg/g, median 110 µg/g, range 8 to 3,341 µg/g) were associated with a geometric mean BLL of 2.5 µg/dL (range 1.3 to 22.5 µg/dL) using the IEUBK model. In Syracuse, New York, soil samples were found to have a geometric mean lead concentration of 80 µg/g, and BLL analysis revealed that 27.6% of the 12,228 children sample (ages 0-6 years) had BLLs above 10 µg/dL (with a geometric mean between 4 and 6 µg/dL, as extrapolated from a graphical figure) (Johnson and Bretsch 2002). In post-Hurricane Katrina New Orleans, children living in areas where soil lead concentrations were less than 100 µg/g were found to have a median BLL of 3.0 µg/dL (Mielke *et al*., 2017).

All of the available soil data for Daniel McIntyre is for public parks and playgrounds and are clustered in certain areas of the neighbourhood. As for each of the neighbourhoods sampled as part of the Provincial investigations, none of the soil samples for Daniel McIntyre have been collected from residential properties.

The data from the 2007/2008 Provincial investigation for the Centennial neighbourhood indicate that soil lead concentrations in the samples range from 4.2 to 307 µg/g, with a median of 74.3 µg/g. All samples were collected from the Dufferin Elementary School (which is located within the Centennial neighbourhood) and no other parks or residential areas were included. Only four (4) additional soil samples were collected in Centennial as part of the 2007/2008 Provincial investigation (from a depth of 0-7.5 cm rather than the shallower depths of 2.5 or 5 cm from the previous investigation), with soil lead concentrations ranging from 38.9 to 59.8 µg/g. One of these four (4) samples was collected from the Dufferin Elementary school. Similar to the neighbourhoods of Daniel McIntyre and Weston, the median soil lead concentration for Centennial is within the range of soil lead concentrations reported in the literature from other urban areas.

The available data for the neighbourhoods of Sargent Park, West End, and Wolseley/Minto suggest that most soil lead concentrations are below the CCME guideline, with a few exceedances evident in Sargent Park, West End, and Wolseley/Minto (Section 2.2). The median soil lead concentrations for Sargent Park (16.9 µg/g), West End (63 µg/g), and Wolseley/Minto (66 µg/g) are all within the range of median soil lead concentrations reported in the literature for other urban areas in Canada, the US and Europe.

No soil sampling data are available from St. Matthews – a neighbourhood directly south of Daniel McIntyre and directly north of Portage Avenue (the TransCanada highway).

Dufferin, River/Osborne, and St. Boniface

The median soil lead concentrations for the neighbourhoods of Dufferin (40 µg/g), River/Osborne (39.5 µg/g), and St. Boniface (42.5 µg/g) were lower than those for many other Winnipeg neighbourhoods and all were within the range of most median soil lead concentrations reported in the literature for other urban areas in Canada and the US.

Although the Dufferin neighbourhood is technically part of the Point Douglas Community Health Area, it is discussed separately in this report since soil lead concentrations in this area (4.2 to 307 µg/g) are notably lower than concentrations in other parts of Point Douglas. As noted in WRHA (2015c), this area is an older part of Winnipeg. As a result, some variation in soil lead concentrations are expected in association with legacy sources of lead (*e.g*. leaded gasoline, lead-based paint, historical industrial emissions).

River/Osborne is considered to be part of the River Heights Community Health Area (WRHA 2015c) and is located to the south of the downtown area and separate from both the neighbourhoods of Dufferin and St. Boniface. The median concentration of 39.5 µg/g is below or within the range of medians reported for other urban areas, and soil concentrations in this area range from 3.7 to 310 µg/g.

The neighbourhood of St. Boniface was studied in the investigations conducted by the Province in 2007/2008 and by the University of Manitoba (2017). Data from these investigations show a median soil lead concentration of 42.5 µg/g, with a range of 4.86 to 1,630 µg/g. Unlike all of the other Winnipeg neighbourhoods described in Figure 5-12, St. Boniface is located on the east side of the Red River.

5.2.3 Socioeconomics and Health Status in Winnipeg Neighbourhoods of Potential Concern

Large urban studies completed by Mielke *et al*. (2011, 2013, 2017), Zahran *et al*. (2011, 2013b), Laidlaw *et al*. (2016, 2017, 2018a,b), and Dong *et al*. (2019) have consistently noted a disparity in lead exposure between low and high sociodemographic areas. To add to the interpretation of the potential risks associated with soil lead concentrations for neighbourhoods in Winnipeg, certain sociodemographic data available from the City of Winnipeg have been considered with the intent of further identifying sub-populations that may be at increased risk. This is not intended to represent a full consideration of all social determinants of health or socioeconomic factors, rather, this overview of available information is aimed at providing additional context to the soil data with respect to potential effects on people living in the identified neighbourhoods.

A report by the Canadian Institute for Health Information (CIHI, 2010) examined urban environments and inequalities in health for the Winnipeg area. The CIHI (2010) study included an evaluation of various factors that influence socioeconomic status and health, and the assessment was based on a framework known as the Institute National De Santé Publique du Québec (INSPQ) Deprivation Index. The INSPQ index was used by CIHI to classify areas within the City of Winnipeg into high, average, and low socioeconomic groups according to two components:

- Material Component, which considers the percentage of individuals who did not graduate high school, employment ratios, and average income; and,
- Social Component, which considers the percentage of single-parent families, individuals living alone, and people who are separated, divorced or widowed.

The maps within Figures 5-13 and 5-14 present colour-coded ratings of the various areas of Winnipeg, with the dark grey areas representing the higher status areas, and the blue and darker blue areas representing the lower status areas. The two figures represent the INSPQ Deprivation Index ratings as determined by CIHI (2010) for the various census areas based on material and social components, respectively. The central area of Winnipeg appears to have the lowest ratings for the social component of this index, while the material component results are more variable. The areas in the more suburban areas generally have higher ratings for both components, with the exception of lower material component ratings in some areas in the northeast and southeast areas of Winnipeg.

There is considerable overlap in the areas presented within these two Figures with the map outlining potential sources of lead and neighbourhoods of potential concern provided in Sections 2 and 3 of this report.

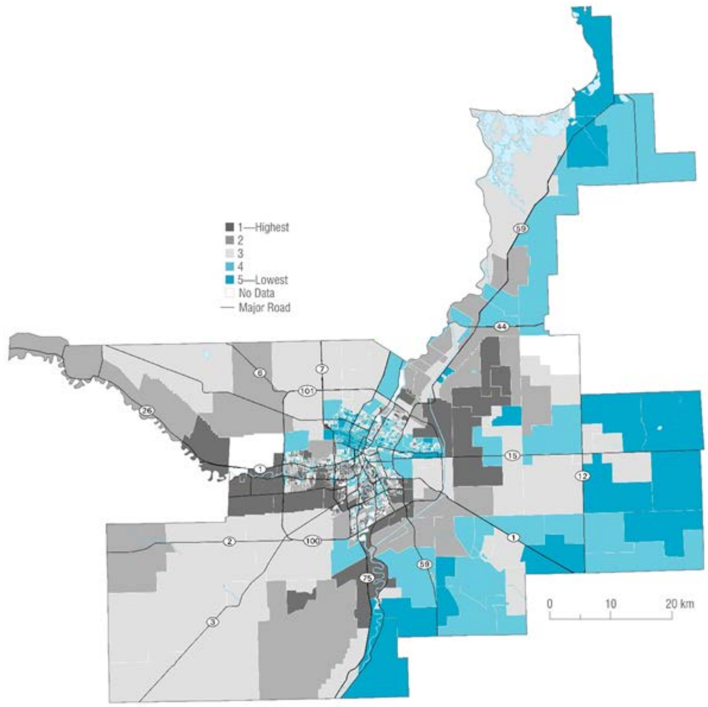


Figure 5-13 Material Component INSPQ Deprivation Index Ratings for the Winnipeg Census Area (CIHI, 2010)

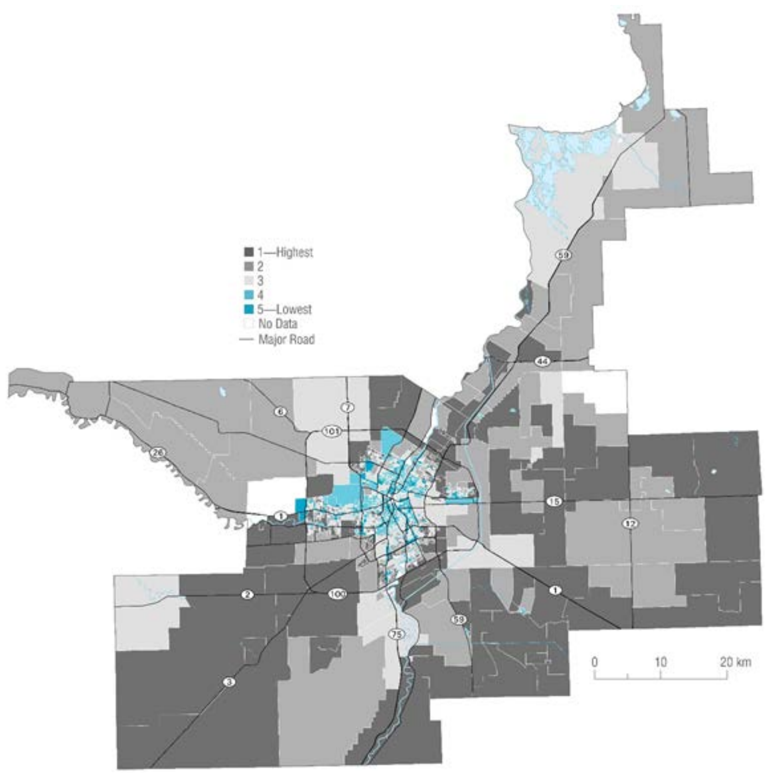


Figure 5-14 Social Component INSPQ Deprivation Index Ratings for the Winnipeg Census Area (CIHI, 2010)

Sections 5.2.3.1 to 5.2.3.2 provide an overview of certain socioeconomic and health statistics that are relevant to the assessment of potential risks to residents of a number of neighbourhoods. The City of Winnipeg has compiled census data collected in the year 2016 by Statistics Canada for various areas of the City. A map of the census areas is provided in Figure 5-15. A summary of potentially relevant parameters is presented in Table 5-9 for the community areas of:

- **Point Douglas** (includes North and South Point Douglas, Dufferin, Lord Selkirk Park, William Whyte, Burrows Central, Inkster-Faraday, Luxton, Mynarski, Robertson, St. Johns and St. Johns Park.
- **Inkster** (includes Weston, Brooklands, Burrows-Keewatin, Shaughnessy Park, Inkster Gardens and Tyndall Park).
- **Downtown** (includes Centennial, Daniel McIntyre, Sargent Park, Wolseley/Minto, St. Matthews, Central Park, Assiniboine, West Alexander, West Broadway and Spence).
- **St. Boniface** (Includes St. Boniface West and St. Boniface Industrial)

While census information for 2016 is available at a community level by the City of Winnipeg, given the uncertainties identified within the data set, the evaluation of the socioeconomic and health impacts is completed at a broader community-area level. This also makes the definition of the areas in Figure 5-15 consistent with data from the Winnipeg Regional Health Authority from 2015, which is discussed according to community area.

Figure 5-15 Map of 2016 Community Census Areas (City of Winnipeg, 2019e)

5.2.3.1 Population Age and Ethnic Characteristics

A summary of available data for the four census areas is presented in Table 5-9, with a focus on total population, proportion of children in the age groups 0-4 and 5-9 years of age, and the relative proportion of individuals identifying as Aboriginal or visible minorities at the time of the 2016 Census. The latter is applicable, as urban studies in the US have identified disparities in both socioeconomic status and racial or ethnic status with respect to the potential for lead exposure.

Table 5-9 Community Area Characteristics based on 2016 Census Data (City of Winnipeg, 2019e)

Characteristic	Point Douglas	Inkster	Downtown	St. Boniface	City of Winnipeg
Total Population	40,795	31,990	66,850	58,520	705,244
Children 0-4 years (% population)	3,005 (7.4%)	2,050 (6.4%)	4,205 (6.3%)	3,385 (5.8%)	40,199 (5.7%)
Children 5-9 years (M+F)	3,135 (7.7%)	2,175 (6.8%)	3,750 (5.6%)	3,550 (6.1%)	40,904 (5.8%)
Aboriginal Identity	29%	16.7%	17.4%	12.1%	12.2%
Visible Minority Group	35.4%	56%	41.4%	18.5%	28%

The available census data indicates that there are several thousand young children living in the identified community areas, and all four of the identified areas had proportions of children ages 0-4 years and 5-9 years greater than what is recorded for the City of Winnipeg as a whole (with the exception of children ages 5-9 in the Downtown area). The youngest of those children, born in 2016, would now be approximately 3-years of age (36 months or more) and the oldest now approximately 7-years of age. Census data for the period between the 2016 census and present are not available for comparison, but it is practical to assume that the proportion of the population within this age bracket is generally similar. Children between the ages of 0 and 6-years of age are considered to be at the highest risk for lead exposure and health impacts.

The 2016 census data also highlights that the proportion of residents identifying as Aboriginal is higher in Point Douglas, Inkster, and Downtown than for the City of Winnipeg as a whole. The difference in proportion is most apparent for Point Douglas, which is reported to include more than double the number of Aboriginal-identifying residents. This is of relevance to the assessment of potential risks associated with exposure to lead as Aboriginal children have been identified as being more vulnerable to the effects of environmental exposures (AFN, 2008). A study published by the Assembly of First Nations in 2008 noted that Aboriginal children are more likely to come from lower socioeconomic backgrounds, to live in homes requiring repairs or with crowded living conditions, have poorer health outcomes, increased health burden, and challenges associated with food quality and security.

The Point Douglas, Inskter and Downtown areas also had relatively higher populations of visible minorities in comparison to the City of Winnipeg as a whole. In contrast, the proportion of visible minorities within the St. Boniface area was lower than the other areas, as well as the City of Winnipeg.

5.2.3.2 Education, Employment, and Income

To compare the general economic status of residents within the four selected community areas, Table 5-10 presents available data from the 2016 census regarding education and employment status, and income. The available data for the City of Winnipeg as a whole is provided for comparison purposes.

Based on this information, the Point Douglas area is of lower socioeconomic status than the other three community areas. Within Point Douglas, residents are generally less educated, based on a higher proportion of individuals without a high school certificate and a lower proportion of individuals with postsecondary education than the other three community areas and the City as a whole. The Point Douglas area also has a lower employment rate, higher unemployment rate, and average and median incomes that are lower than the other community areas and the City of Winnipeg.

For Inkster and Downtown, the proportions of individuals with an education level of high school or higher are more comparable to the overall rates for the City of Winnipeg, as are the employment and unemployment rates. The average and median incomes for Inkster and Downtown are lower than for the City of Winnipeg as a whole.

Based on the 2016 census data, St. Boniface residents have education levels comparable to, or above, values for the City of Winnipeg as a whole. The rate of employment is higher than for the City, and the unemployment rate is lower. Both average and median incomes within St. Boniface are higher than the values for the City of Winnipeg. This data suggests that St. Boniface is of higher socioeconomic status than the other three community areas.

Table 5-10 Comparison of Education, Employment, and Income Statistics from 2016 Census Data (City of Winnipeg, 2019e)

Characteristic	**Point Douglas**	**Inkster**	**Downtown**	**St. Boniface**	**City of Winnipeg**
Highest Education Level Achieved					
Less than Highschool	30.7%	23.4%	21.7%	14.5%	17%
Highschool or equivalent	29.9%	31.0%	27.8%	29.3%	29.9%
Postsecondary	39.5%	45.6%	50.5%	56.2%	53.2%
Work					
Employment Rate	55%	62%	61%	66%	63%
Unemployment Rate	10%	7%	8%	6%	7%
Average Income in 2015	$29,627	$33,430	$33,261	$98,630	$44,915
Median Income in 2015	$26,218	$30,417	$26,819	$80,661	$35,121

5.2.3.3 Health Status

The Winnipeg Regional Health Authority (WRHA) has published profiles for various communities within the City. Information regarding health status and select determinants of health are discussed for Point Douglas, Inkster, Downtown and St. Boniface below.

Point Douglas

The WRHA profile for Point Douglas (2015c) notes that community engagement events in the area have identified issues of concern as including: low education levels, limited job opportunities, food insecurity, access to stable housing, available day care spaces, access to walk-in doctors, and limited transportation funding. For various indicators of health status (*e.g.*, disease prevalence, birth weight, mortality rates, life expectancy), Point Douglas was rated as significantly worse than Winnipeg as a whole. For behavioural indicators (*e.g.*, diet and lifestyle), Point Douglas also generally rated as significantly worse than Winnipeg as a whole.

With respect to health care access, the rating on the various indicators was more variable, with some outcomes being similar to Winnipeg and others worse than Winnipeg.

A lower proportion of Point Douglas residents (42%) rate their health as being excellent, compared to 58% of total Winnipeg residents. The rates of certain diseases in Point Douglas (specifically, stroke rate per 1,000, respiratory diseases, diabetes, heart disease, hypertension and dementia) are higher than for the City of Winnipeg. The percentage of low-birth weight infants has been increasing in Point Douglas over time. Early Development Instrument (EDI) scores for children are used to determine "readiness for school" in young children. The percentage of children within Point Douglas that are deemed to be "not ready for school" based on two or more EDI domains has increased since 2005, and at 24.3% is a higher proportion of children compared to the percentage of children in Winnipeg with this classification (14.8%). The WRHA (2015c) report for Point Douglas also notes that community members have shared their concerns regarding parenting skills, adverse exposure during pregnancy, the intervention of child services, lack of mental health care and dental care, high levels of domestic violence, and access to quality childcare.

Inkster

According to the WRHA profile for Inkster, community members have identified concerns in the areas of employment and income, education, transportation, mental health services for youth, and food access (WRHA, 2015b). For various health status indicators (*e.g.*, disease prevalence, mortality, life expectancy, mortality, etc.), the outcomes for Inkster were variable in comparison to the City as a whole. For premature mortality, rates of respiratory disease, hypertension, diabetes and heart disease, the Inkster ratings were significantly worse than for Winnipeg. However, for dementia, osteoporosis, general mental health and mood/anxiety disorders, Inkster was significantly better than Winnipeg. For behavioural indicators (*e.g.*, diet and lifestyle), Inkster residents were found to be similar or better than Winnipeg as a whole. However, for health care access, the ratings for Inkster were generally worse than for Winnipeg, with the exceptions of hospitalization care and benzodiazepine treatment (WRHA, 2015b).

With respect to children and family, the percentage of low-birth weight infants in Inkster has decreased over the years, but at 6% remains slightly higher than the Winnipeg rate of 5.8%. The percentage of children identified as being "not ready for school" has remained at about 14% since 2005 within Inkster, just slightly lower than the percentage for Winnipeg of 14.5% (WRHA, 2015b). Residents of Inkster have identified shortcomings in the areas of education quality, access to quality childcare, access to city and social services, lack of mental health care and crisis response, and access to healthy and affordable food (WRHA, 2015b).

Downtown

Residents of the Downtown community health area have identified issues of concern as being low socioeconomic conditions, poverty, and a lack of education, employment, quality childcare, affordable housing and supports for newcomers to the City (WRHA, 2015a). The WRHA (2015a) profile for the Downtown area noted that for several health indicators (disease prevalence, mortality, life expectancy, mortality etc.), the statistics for the Downtown area were rated as being worse than for the City of Winnipeg as a whole. However, the ratings for some indicators, such as heart disease incidence and prevalence, stroke events, mood and anxiety disorders and osteoporosis were found to be comparable to the City of Winnipeg. For behavioural indicators relating to diet and lifestyle, the Downtown area was found to be comparable to the City of Winnipeg. Access and use of physicians in the Downtown area were found to be comparable to the rest of the City. However, for access to health care, lower ratings were given for cancer screening, prenatal care, and hospitalizations for the Downtown area (WRHA, 2015a). The proportion of low birth weight infants in the Downtown area was determined to be higher at 6.5% compared to 5.8% for Winnipeg. The percentage of children classified as “not being ready for school” was also found to be higher for Downtown residents (20.7%) compared to the proportion for Winnipeg (14.8%).

Other concerns raised by the community noted within WRHA (2015a) include lack of access to quality educational facilities that are convenient, low adult literacy funding, generational poverty, food insecurity, lack of childcare and activities for children, limited mental health care support, and limited resources for language support for newcomers.

St. Boniface

The residents of St. Boniface consider themselves to generally be a healthy community. There is a strong presence of French-speaking individuals, and overall there is a lower proportion of low-income residents. The results of the WRHA (2015d) assessment profile for St. Boniface indicates that area residents are rating comparable or better than the City of Winnipeg with respect to all health and behavioural indicators. With respect to health care access, in general, St. Boniface scored better or comparable to the City of Winnipeg in all areas except benzodiazepine treatment (WRHA, 2015d).

A lower proportion of infants with low birth weight (5.2%) are born to St. Boniface residents in relation to the City of Winnipeg (5.8%). The percentage of children rated “not ready for school” in St. Boniface (8.7%) is better than for the City of Winnipeg as a whole (14.8%).

Concerns raised by area residents include a lack of quality affordable housing for seniors and newcomers, provision and access to mental health care services in both English and French, access to quality childcare, and limited public transportation access in East St. Boniface (WRHA, 2015d).

5.2.3.4 Summary of Socioeconomics and Health Status for Winnipeg Neighbourhoods of Potential Concern

The three census/community health areas (Point Douglas, Downtown, and Inkster) identified as including neighbourhoods with elevated soil lead concentrations all have comparatively lower socioeconomic and health status than the City of Winnipeg as a whole. These three areas include the neighbourhoods of North Point Douglas, Weston, Daniel McIntyre and Centennial.

All three of these areas share the characteristics of:

- Higher proportion of children within the age groups of 0-4 and 5-9 years of age;
- Higher proportion of Aboriginal and visible minority residents;
- Lower education achievement;
- Lower employment and higher unemployment;
- Lower average and median income;
- Expressed need for mental health care and social supports;
- Poorer ratings than for the City of Winnipeg for several indicators of health, behaviour and health care access;

- Greater proportion of children affected by lower birth weights, and being assigned the classification as “not ready for school” than for the City of Winnipeg; and,
- Expressed need for improved access to quality childcare and education resources.

As a result, the children residing in the Point Douglas, Downtown, and Inkster areas may be more vulnerable to the effects of lead exposure. The census/community health area of St. Boniface scored better on all socioeconomic and health indicators than the other three identified areas.

5.3 Conclusions, Data Gaps, and Uncertainties Associated with Task 4

There is inherent uncertainty associated with the comparison of soil lead data across studies due to the differences in sampling design, digestion and analysis, and the statistics available in the published papers. In some instances, medians were not available, and geometric means or averages were used for data points in Figure 5-12. The data within this Figure are intended for general comparative purposes only.

Significant gaps in the soil data are apparent in the areas immediately surrounding the railway line, particularly on the north side between McPhillips and Main Streets, to the north of Dufferin and Dufferin Industrial. This area includes a large portion of the Point Douglas Community Health Area and an area of the City known as the ‘north end’. While data for North Point Douglas, Dufferin, and Dufferin industrial, and a few data points for South Point Douglas are available, there is an overall lack of coverage. These data gaps are notable for several reasons:

- These are residential areas where young children are present (based on census data).
- The vast majority of samples collected to date have consisted of residential boulevards adjacent to roadways, rather than residences, community centres, and areas where children may actually be present on a frequent and prolonged basis.
- Based on the available soil data and the IEUBK model, BLLs predicted for children ages 7 years and under in North Point Douglas have a 97% probability of being greater than 2 µg/dL, with an estimated 95th percentile of 10 µg/dL and geometric mean of 4.7 µg/dL. For comparison purposes, the geometric means for Canadian children ages 3-5 and 6-11 years based on monitoring data from 2016-2017 are 0.56 and 0.54 µg/dL, respectively (Health Canada, 2019b). Also, the 95th percentile for BLLs in the City of New Orleans in children under the age of 6 years before hurricane Katrina (data for years 2001-2005) was 7.5 µg/dL (Mielke *et al*., 2013). Several adverse health and societal outcomes have been found to be associated with elevated BLLs within New Orleans (Mielke *et al*., 2013), which are potentially relevant to the North Point Douglas neighbourhood based on the available data and the lack of data coverage for adjacent neighbourhoods. While the modelled results only represent preliminary estimations, the findings signal a need for additional study.
- The area is considered to have a low socioeconomic status, has high unemployment, and generally poorer health. The Point Douglas area also has a sizeable Indigenous population (approximately 30%).
- The area is among the oldest in Winnipeg, includes present and historical industrial sites, major traffic thoroughfares, and may have been impacted to a greater extent than other areas of the City by leaded gasoline, coal combustion (for heating and previous industry) and leaded paint on both interior and exterior structures.

- This area of Winnipeg is identified as potentially being serviced by lead-containing water distribution systems. As a result, it is possible that lead exposures from drinking water are higher than modelled by IEUBK.

The Weston area data set is also affected by the lack of residential samples. All available data are for samples collected from the elementary school or sports field, and a few playgrounds. While these are of relevance to school-aged children, they do not necessarily capture the exposures that children under the age of 6 years may be receiving at home or in childcare. The data is clustered and does not provide full coverage of the neighbourhood as a whole. Further, numerous samples for Weston were collected at a depth of 0-7.5 cm rather than 5 cm or less. These data gaps are notable due to:

- The age of the neighbourhood, the noted proximity to historical emissions sources, including a now inactive smelter as well as a railway, and proximity to roads and structures that may contain leaded paint.
- Based on the available soil data set, the predicted geometric mean BLL for children 7 years and below is 2.6 µg/dL, and the estimated 95th percentile is 5.6 µg/dL. The IEUBK model estimates that the there is a 70% probability that children within this age group may have a BLL above 2 µg/dL.
- The sociodemographic data for the Inkster census area, of which Weston is part, indicates that the ratings for some health indicators, including access to health care, are lower than for the City of Winnipeg.
- The Weston area, as well as other parts of the Inkster Community Health area, are within the area highlighted in Figure 3-7 as potentially being affected by water distribution systems affected by lead components. As a result, it is possible that drinking water lead exposures are higher than predicted.

There are some notable data gaps for the neighbourhoods within the Downtown area of Winnipeg. As noted previously, all of the available information for Daniel McIntyre (also considered be part of the Downtown Community Health area) is clustered within area parks, without any coverage of residential areas. Most of the soil data available for the neighbourhood of Centennial was collected from the Dufferin Elementary School and did not include areas more representative of residential exposures to which young children could be exposed. Several samples were collected in Wolseley/Minto and Sargent Park from schools, community centres and residential boulevards, however, no samples have been collected from residential properties in these areas either. No residential area data are available for the other areas that fall within the Downtown Community Health Area – Central Park, Assiniboine, West Alexander, West Broadway and Spence or St. Matthews (located to the south). While it is acknowledged that this area is less residential than some of the other neighbourhoods evaluated, the 2016 census data indicates that there are children residing in these areas. This lack of data coverage is notable given:

- The age of the area and the associated potential for legacy impacts from leaded gasoline, leaded paint, and historical industrial emissions.
- The available data for Daniel McIntyre and Centennial demonstrates median lead concentrations are within the upper range reported in the literature for other urban areas.
- The predicted geometric mean BLLs for children aged 7 years and under in the Downtown neighbourhoods of Daniel McIntyre, Sargent Park, Wolseley/Minto, and Centennial are 1.8, 1.3, 1.2, and 1.5 µg/dL, respectively. The IEUBK model predicts that

the probability of exceeding a BLL of 2 µg/dL is 41%, 20%, 12%, and 27% for these neighbourhoods, respectively.

- The ratings for several health indicators for Downtown residents were lower than for the City of Winnipeg as a whole. Higher proportions of children with low birth weights and classifications as “not being ready for school” were identified in the Downtown area.
- These areas fall within the region highlighted as potentially being serviced by lead water distribution infrastructure. As a result, the exposures from drinking water may be higher than predicted in some of these neighbourhoods.

The data set for the neighbourhood of St. Boniface is the largest out of all of the communities evaluated in this assessment. The St. Boniface data from both the 2018 Provincial investigation and the University of Manitoba (2017) investigation are focused on soil samples from a depth of 0-7.5 or 0-10 cm, rather than less than 5 cm as recommended by the US EPA (2003) for the health assessment of lead. Soil sample locations were inconsistent, with many of the St. Boniface samples collected from gardens. It is likely that garden soils are amended to some extent with soils obtained from other areas (*e.g.*, topsoil, manure, compost, mulch, etc.) and as a result, use of these samples to represent soil lead concentrations on a given property may underestimate the potential exposure opportunities for children that may spend a greater percentage of their time playing in areas (*e.g.*, front or backyard grassed areas) with higher soil lead concentrations.

6.0 TASK 5: RECOMMENDATIONS FOR FURTHER ASSESSMENT OF RISKS AND PROPOSED RISK MANAGEMENT AND RISK COMMUNICATION OPTIONS

To aid the Government of Manitoba in identifying future actions to address lead in Winnipeg soils, a general overview of potential options was conducted. This discussion focused on approaches for further investigation and risk management, including:

- Development of site-specific soil remediation criteria for Winnipeg;
- Completion of a human health risk assessment;
- Biomonitoring and environmental sampling;
- Soil remediation and risk mitigation;
- Personal and community level interventions; and,
- Evaluation of other risk mitigation options through regulatory frameworks.

A summary of intervention strategies utilized by government and industry is also provided, along with a discussion of methods used for risk communication.

6.1 Summary of the Findings of Task 5

The overall findings of this task are as follows:

- Preliminary calculations were made for site-specific remediation criteria based on a range of recently endorsed non-threshold based TRVs. Due to a lack of site-specific information regarding the bioaccessibility of lead in Winnipeg soils, a range in literature-based bioaccessibility estimates were used. This resulted in a range of values for a residential soil criterion of 100 to 210 µg/g to be protective of neurodevelopmental effects in children. While these values are derived using the standard CCME approach for non-threshold contaminants and are based on central tendency estimates, regulators may decide to utilize alternative approaches in future guideline development which account for probability distributions of BLLs, such as those estimated using the IEUBK model. Use of this type of approach may result in a residential soil lead criterion well below 100 µg/g.

- Based on the information available to describe lead content in soils in various neighbourhoods throughout Winnipeg, the completion of a quantitative HHRA is unlikely to provide significant further insight into the interpretation of potential risks. Additional investigations focusing on characterizing the distribution and bioaccessibility of lead in soils, as well as lead content in other environmental media such as indoor dust, at-tap drinking water, and painted surfaces, would be required to realize the full potential benefits of conducting a detailed HHRA. Alternatively, a biomonitoring study paired with residential environmental sampling is anticipated to provide greater value and insight regarding lead exposures experienced by children in areas of concern.

- Several potential risk management and remediation activities are available for lead. Each option is associated with various benefits and challenges and should be considered carefully with respect to the potential risks and benefits of implementing these options on a site-by-site basis.

- Information available from case studies and the literature suggest that a reduction in the source of lead exposure within communities through emission reduction or elimination, or soil-capping/remediation are the most effective measures for reducing BLLs. Household abatement, indoor dust management and hygiene practices appear to be generally less effective when used on their own. Given that the primary sources of lead contamination for Winnipeg soils have been eliminated (*e.g.*, leaded fuels, secondary lead smelters), further source reduction would likely be limited to isolated commercial/industrial operations.

- There may be benefits for elevated BLLs in children to be monitored and tracked at a community or provincial level to aid in the identification of children at risk as well as highlighting high-risk areas.

Overall, using multiple lines of evidence, including characterizing the frequency and magnitude of exceedances of health-based soil criteria, theoretical modelling of BLLs, and extrapolation of empirical data to relate soil concentrations to potential BLLs in Winnipeg children, the assessment of potential risks associated with soil lead concentrations indicates that further study may be warranted. Given that there are sufficient data to demonstrate that soil contamination in certain neighbourhoods represents a potential concern, blood lead monitoring is recommended as an effective approach for assessing risks and the potential need for further soil sampling and/or the implementation of risk management measures.

In addition to the collection of blood for lead analysis from children under the age of 7 years, a detailed questionnaire for participants is recommended to collect information about their environment and various personal factors that may influence exposure to lead. The collection of environmental samples from individual households of participants can also be included as part of the study to examine the potential influence of various environmental media on levels of internal exposure.

6.2 Approaches for Further Assessment of Potential Risks

Consideration of additional approaches for the further assessment of potential risks associated with lead in soils in Winnipeg included the derivation of soil remediation criteria, a detailed human health risk assessment, and blood lead monitoring.

6.2.1 Derivation of Soil Remediation Criteria

Concentrations of lead in soil samples collected from Winnipeg neighbourhoods were compared to the CCME soil quality guideline of 140 µg/g as an initial assessment of potential risks and to characterize the distribution and magnitude of soil contamination that may be of concern. As described previously, there have been significant changes in the understanding of the toxicological effects of lead in children and adults since the derivation of the CCME SQGs for lead in 1999. Many regulatory agencies have updated their respective health-based policies and guidelines concerning lead stemming from the evolving science on the toxicology of lead which indicates that a threshold for effects cannot be determined, and hence, there is risk at any level of exposure (Health Canada, 2013a; US EPA, 2006; WHO, 2010c, JECFA, 2011).

The derivation of a health-based soil quality criterion, which can be used to represent a remediation threshold, should consider factors such as the identification of an appropriate toxicity reference value, the bioaccessibility of lead in ingested soils, and exposure frequencies reflective of specific property uses and seasonal weather conditions. Each of these factors are discussed below.

6.2.1.1 Selection of an Appropriate Toxicity Reference Value

Several agencies, including Health Canada (2013a), have indicated that the relationship between IQ score (in children) and BLLs is the strongest line of evidence of adverse effects in humans at BLLs less than 10 µg/dL. Health Canada has concluded that selecting children as the most susceptible subpopulation, and neurodevelopmental effects as the most critical endpoint, was protective of other adverse effects of lead exposure (*i.e.*, cardiovascular, renal, and reproductive effects) across the entire population.

Wilson and Richardson (2013) and SNC Lavalin (2012) recommended that a daily lead dose of 0.6 µg/kg-day is associated with a decrement of 1 IQ point in the population. It is noted by SNC Lavalin (2012) that this value should be considered as a *de minimis* population level effect which could likely never be detected in an individual child. In support of the revised lead drinking water quality guideline, Health Canada (2019a) identified a benchmark dose of 0.4 µg/kg-day which was obtained from PBPK and blood lead modelling completed by the EFSA (2010) as part of an assessment of lead in food. Data from Lanphear *et al*. (2005) were analysed by EFSA (2010) and the BLL associated with a 1% response threshold from BMD analysis was identified as 1.2 µg/dL. This 1% response threshold corresponds to a change in population IQ equal to 1 point. The EFSA (2010) then employed blood-lead models and determined that a BLL of 1.2 µg/dL was associated with a daily intake ranging from 0.4 to 0.6 µg/kg-day. Health Canada (2019a) notes that it selected the lowest value in this range as a POD for the drinking water guideline derivation, which was based on the US EPA's IEUBK model.

Although at this time Health Canada does not have a recommended TRV for lead for use at contaminated sites, it is reasonable to assume that the BMD of 0.4 µg/kg-day used in the derivation of the recent Federal drinking water quality guideline is consistent with current Federal policy. As such, this value was selected for the derivation of an updated health-based SQG below. The effect of using a TRV at the high end of the range considered by Health Canada (0.6 µg/kg-day) was also evaluated.

6.2.1.2 Bioaccessibility of Lead in Soils

Incidental ingestion of soils is often considered to represent a major route of potential exposure to metals such as lead. Consideration of the bioavailability of lead in ingested soils is an important factor when estimating exposure and deriving risk-based soil guidelines. Bioavailability is the fraction of a chemical which is ingested, inhaled, or applied on the skin surface that is absorbed and reaches systemic circulation (Kelley *et al*., 2002). The assessment of oral bioavailability of lead and other contaminants can typically be divided into four fundamental processes: i) the oral intake of lead in soil/dust; ii) bioaccessibility; iii) intestinal absorption; and, iv) metabolism in the liver/intestines (Oomen *et al*., 2006; Sips *et al*., 2001). The inclusion of bioaccessibility testing allows for a more realistic estimate of the systemic exposure to lead from soil and dust ingestion rather than using generic assumptions such as those typically used in the derivation of soil quality guidelines. To date, no bioaccessibility analyses have been completed for lead in the soils of Winnipeg neighbourhoods identified within this report. As a result, it is difficult to make informed assumptions regarding lead uptake in the derivation of site-specific guidelines.

Bioaccessibility is the fraction or percentage of lead that is released from soil following ingestion and is available in the gastrointestinal tract for absorptive transport mechanisms (ATSDR, 2019). This fraction represents the upper limit of bioavailability. When bioaccessibility is low, oral bioavailability will also be low. There are two types of bioavailability: absolute and relative. The absolute bioavailability (ABA) is the amount of lead that is expressed as a fraction or percentage of lead ingested that reaches systemic circulation. The relative bioavailability (RBA) is the ratio of ABA of lead in a test material (*e.g*., soil) to the ABA for a reference material (*e.g*., lead acetate) (ATSDR, 2019).

Animal studies (*i.e*., *in vivo* studies) were traditionally used to determine the relative bioavailability of metals; however, there can be significant restraints related to the time, costs, and ethical considerations of these studies. Therefore, more rapid and inexpensive *in vitro* extraction studies (designed to simulate the human stomach and intestinal system) have been developed to provide a reasonable, yet conservative, approximation of true bioavailability by assuming relative bioavailability is equal to bioaccessibility. *In vitro* extraction studies have been designed to simulate the human gastrointestinal tract (*e.g*., pH, temperature, and chemical composition of solutions in both the stomach and small intestine, *etc*.) in order to assess the release of compounds from soil during the digestion process.

While *in vitro* bioaccessibility data can be used to estimate *in vivo* RBA, there are a number of uncertainties associated with this approach, arising from the use of different methods, inter-laboratory variability, model selection, and biomarkers (Dong *et al*., 2016). Dong *et al*. (2016) completed a systematic review of published literature to identify bioaccessibility and bioavailability data for lead, with the aim of estimating lead RBA with respect to soil type to aid in risk assessment and management. In addition, Dong *et al*. (2016) completed sampling and developed RBAs which were classified into four categories based on the known sources of lead at the sites sampled: residential land, mining and smelting sites, house dust, and others (*e.g.* shooting range, incinerator, landfill, gasworks). The RBAs were highly variable among different sources of lead, with median values for residential land, mining and smelting soils, house dust, and other types of soils predicted to be 58%, 26%, 44%, and 45%, respectively (Dong *et al*. 2016) (Figure 6-1).

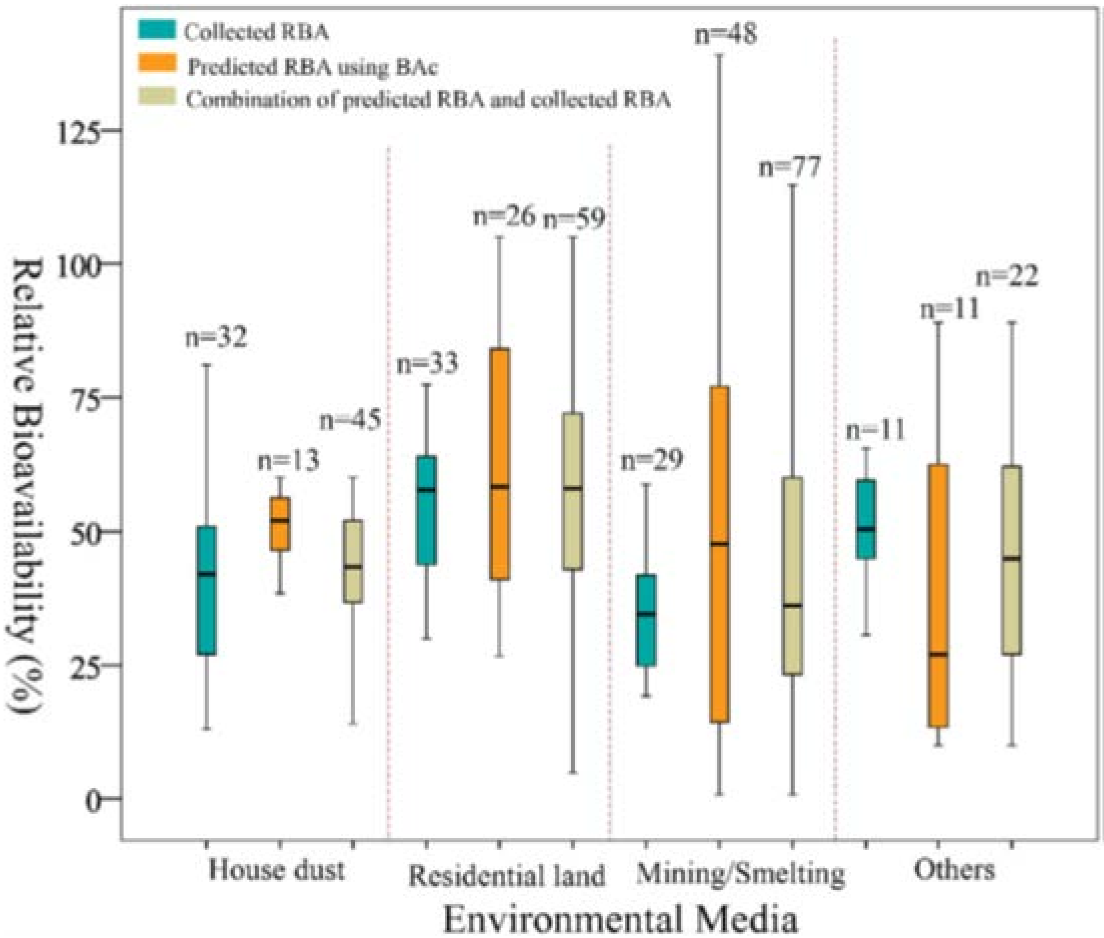


Figure 6-1 Relative bioavailability of lead in soils and dust (Dong *et al*., 2016).

Several studies have compared the results of *in vitro* testing to those provided using *in vivo* methods and derived correlations between these results. It is generally recommended that site-specific *in vitro* bioaccessibility results are adjusted using these identified correlations to more accurately estimate bioavailability. The estimated bioavailability can be used in the assessment of risks associated with lead exposure, and in the derivation of site-specific soil quality guidelines or clean-up criteria (Dong *et al*., 2016).

A review by Henry *et al*. (2015) concluded that combining bioavailability-based decisions with cost-effective, *in situ* remediation is a practical solution for urban soils. However, it is noted that variability in soil composition can impact the results of *in vitro* bioaccessibility tests as well as the effectiveness of soil amendments. Henry *et al.* (2015) also noted that the use of *in vivo-in vitro* correlation tests (IVIVC) must have a linear relationship apparent between *in vivo* and *in vitro* data, with a correlation coefficient (r value) of more than 0.8, and a slope of > 0.8 (initial correlation) and < 1.2 (subsequent validation data sets), and a "within laboratory repeatability" of < 10% relative standard deviation (RSD) for *in vivo* and *in vitro* assays. Also, a "between laboratory reproducibility" of < 20% RSD must be achieved for the *in vivo* and *in vitro* assays being used (Henry *et al.*, 2015). Currently, the three (3) methods that meet each of these criteria include:

- Relative Bioaccessiblity Leaching Procedure (RBALP), also called the Solubility/Bioavailability Research Consortium (SBRC), or US EPA Method 1340;
- Physiologically-Based Extraction Test (PBET); and,
- BARGE method from the Unified Bioaccessibility Research Group of Europe Method (UBM).

Yang *et al*. (2015) used the US EPA IEUBK model along with site-specific measurements of bioaccessibility and soil chemical composition in various zones near a mine site in Broken Hill Australia. The bioaccessibility of lead was found to be associated with total lead concentrations in soil, which were higher with decreasing distance to the mine site. Lead bioaccessibility was observed to increase in soil with higher organic matter (Yang *et al*., 2015). The lead bioaccessibility measurements were used to predict relative bioavailability, from which absolute bioavailability was predicted. The IEUBK model was used to estimate BLLs in relation to topsoil lead concentrations and the estimated bioavailability. The results produced were generally comparable to the blood lead monitoring results in children ages 1-4 years from the community.

The completion of bioaccessibility testing for Winnipeg soils may allow for refinement of the BLLs predicted using the IEUBK model, as well as the development of site-specific remediation guidelines. Given that the sources of lead may differ among areas throughout Winnipeg (*e.g*., smelters, vehicle emissions, scrap yards), bioaccessibility results and the associated remediation guidelines may differ from neighbourhood to neighbourhood.

To date, recommendations for an oral relative absorption factor for lead in ingested soils have varied widely, from 0.6 as used within the IEUBK model to 1.0 as used by Health Canada (1996) in the derivation of a Federal soil quality guideline. The Tri-National Survey measured bioaccessibility of lead in Canadian soils and reported a mean of 39% and a maximum of 93% (Dodd and Wilson, 2011). The maximum value of 93% is consistent with the results of an IVBA conducted for residential soils in urban neighbourhoods in Philadelphia, Pennsylvania with a history of soil lead contamination which found a mean and median bioaccessibility of 93% (Bradham *et al*., 2017).

Wilson and Richardson (2013) selected a factor equal to the 95th percentile (74%) from the Tri-National Survey in the derivation of an SQG. A range in values of 74% to 93% may be appropriate for use in the absence of a site-specific value.

6.2.1.3 Exposure Frequencies

The incidental ingestion of outdoor soil and indoor dust represents a significant source of exposure to lead. Fine particles of surface soil and household dust adhere to the fingers of children and are ingested through typical hand-to-mouth activities (US EPA, 1994). Standard daily ingestion rates are provided by regulatory agencies such as the CCME and Health Canada and represent the total amount of outdoor soil and/or indoor dust ingested throughout the year. During colder months when access to outdoor soil is restricted by snow and frozen ground, and children are likely to spend less time outdoors, a greater proportion of the daily soil/dust ingestion may be attributed to household dust. Although children have greater access to outdoor soils during the summer months, it is assumed that a notable amount of the daily exposure would still be attributed to ingestion of household dust, particularly for very young children that may spend more time indoors.

Within the Winnipeg area, the period of the year without snow is reported to last for 180 days, from April 27th to October 19th (Weatherspark, 2019). This equals 180 days per year without snow and 185 days with snow, a nearly 50/50 ratio. Although the IEUBK model does not account for factors related to climate, this ratio is similar to the default soil/dust weighting factor (45/55) which assumes that 45% of the daily ingestion rate is attributed to outdoor soil.

When measured concentrations of lead in household dust are not available, the IEUBK model uses the Multiple Source Analysis (MSA) module to predict concentrations of lead in dust. This involves assigning a value to represent the mass fraction (MSD) of house dust that is derived from outdoor soil. The IEUBK default value for MSD is 0.70 g soil/g dust. In addition to the contribution of outdoor soil to indoor dust lead levels, the contribution of impacted outdoor air is also considered in the MSA. An additive increment of 100 µg/g of lead in indoor dust for every 1 µg/m^3 of lead in outdoor air is added to the contribution from outdoor soil. Given that the average concentration of lead measured in outdoor air in Winnipeg is 0.002 µg/m^3, the contribution of outdoor air to lead in household dust is negligible (*i.e.*, 100 x 0.002 = 0.2 µg/g). Therefore, concentrations of lead in household dust in Winnipeg would be predicted to be 70% of the concentration measured in outdoor soil. It is important to note that this does not account for contributions of lead from other sources such as lead-based paint, and that even during the winter months when access to soil is restricted, the household dust lead concentrations continue to be influenced by outdoor soil.

The derivation of a soil remediation threshold (or soil quality guideline) could potentially be adjusted in an attempt to account for the colder Winnipeg climate relative to other parts of Canada and the US. The derivation of the CCME soil quality guidelines generally do not account for the potential that 50% of the annual soil/dust ingested could be household dust which has lead concentrations that are 30% lower than outdoor soil concentrations. Making this adjustment in the derivation of a soil guideline would effectively increase the guideline by 15% relative to a guideline derived assuming year-round exposure to soil only.

6.2.1.4 Derivation of an Updated Health-Based Soil Quality Guideline

A health-based SQG was derived using the CCME approach for non-threshold contaminants and a risk-specific dose (RSD) of 0.4 µg/kg-day. For the initial SQG calculation, all parameters describing body weight, relative absorption factors (gut, skin, and lung), soil ingestion, dermal contact, background soil concentration, inhalation rate, and exposure frequency and duration were consistent with those utilized under the Federal framework, as follows:

$$SQG_{HH} = \frac{RSD \times BW}{[(AF_G \times SIR) + (AF_S \times SR) + (AF_L \times IR_S) \times ET_2] \times ET_1} + BSC$$

where:

SQG_{HH}	=	Human health-based soil quality guideline (µg/g)
RSD	=	Risk specific dose (toddler: 0.4 µg/kg/day; Health Canada, 2019a)
BW	=	Body weight (toddler: 16.5 kg; Health Canada 2012)
BSC	=	Background lead concentration in soil (10 µg/kg; Health Canada, 2013a)
AF_G	=	Relative absorption factor for gut (0.93; Dodd and Wilson, 2011)
AF_S	=	Relative absorption factor for skin (0.006; Health Canada, 2010)
AF_L	=	Relative absorption factor for lung (1.0; Health Canada, 2012)
SIR	=	Soil ingestion rate (toddler: 8.0×10^{-5} kg/day; Health Canada, 2012)
SR	=	Soil dermal contact rate (toddler: 6.9×10^{-5} kg/day; Health Canada, 2012)

IR_S = Soil inhalation rate (toddler: 6.3x10^{-9} kg/day; Health Canada, 2012)
E_{T1} = Exposure term 1 (unitless) for all pathways – 7/7 days x 52/52 weeks (for residential/parkland land use (Health Canada, 2012; CCME, 2006))
E_{T2} = Exposure term 2 (unitless) for the inhalation pathway – 24/24 hours (for residential/parkland land use (Health Canada, 2012; CCME, 2006))

Based on the above equation and a Risk Specific Dose (RSD) of 0.4 µg/kg/day (Health Canada, 2019a), the residential lead SQG for the toddler was calculated to be 100 µg/g. Using an RSD of 0.6 µg/kg/day would result in an SQG of 140 µg/g, equal to the current CCME residential SQG. These guidelines were derived using an oral relative absorption factor of 0.93. Using a factor of 0.74 would result in guidelines protective of the toddler of 120 and 180 µg/g using RSDs of 0.4 and 0.6 µg/kg/day, respectively. This overall range of 100 to 180 µg/g could potentially increase by a factor of 15% to 115 to 210 µg/g to account for restricted access to soil during the colder months.

While these guidelines are derived using the standard CCME approach for non-threshold contaminants and are based on central tendency estimates, regulators may decide to utilize alternative approaches in future guideline development which account for probability distributions of BLLs such as those estimated using the IEUBK model. Use of this type of approach may result in a residential soil lead guideline well below 100 µg/g.

6.2.2 Human Health Risk Assessment

An HHRA is a scientific study that evaluates the potential for the occurrence of adverse health effects from exposures of receptors to chemicals of concern present in surrounding environmental media (*e.g*., air, outdoor soil, indoor dust, surface water, food and biota, etc.). HHRA procedures are based on the fundamental dose-response principle of toxicology.

The use of HHRA is an effective tool for not only assessing potential risks to people, but also for identifying those pathways that represent the greatest potential source of exposure. Utilizing the available data characterizing lead concentrations in soils in Winnipeg, exposure and risk calculations can consider the bioaccessibility of lead in ingested soils, restricted opportunities for exposure related to snow cover, and contamination depth profiles.

However, the completion of a detailed HHRA is not expected to significantly add to the understanding of the potential exposure and risks to children in Winnipeg. Additional studies would be required to further characterize lead concentrations in soils and other environmental media in neighbourhoods throughout Winnipeg. Due to the identified data gaps in relation to existing soil quality data, potential exposures from house dust and lead paint, and the potential for variability in lead concentrations in tap water, a study evaluating actual exposures that children living in these neighbourhoods are receiving would likely be of greater value than a quantitative HHRA. The completion of an HHRA is further complicated by the non-threshold toxicity characteristics of lead, and the absence of currently endorsed TRVs by Canadian or other jurisdictional authorities. Blood lead monitoring as an alternative to risk assessment for an evaluation of actual lead exposures is described in Section 6.2.3.

6.2.3 Blood Lead Monitoring and Paired Environmental Sampling

Using multiple lines of evidence, including characterizing the frequency and magnitude of exceedances of health-based soil criteria, theoretical modelling of BLLs, and extrapolation of empirical data to relate soil concentrations to potential BLLs in Winnipeg children, the assessment of potential risks associated with soil lead concentrations indicates that further study may be warranted. Since there is limited or no soil data available for many neighbourhoods to allow for a comprehensive characterization of soil lead contamination, further soil sampling may be beneficial. However, given that there are sufficient data to demonstrate that soil contamination in certain neighbourhoods represents a potential concern, blood lead monitoring may be a more effective approach for assessing the need for further soil sampling in certain areas.

Although there are numerous options for the implementation of risk management measures (as described in Sections 4.2.6 and 6.3), the results of several studies indicate that educational interventions and dust abatement have limited effectiveness in reducing BLLs. There is also limited evidence to indicate that soil abatement (removal and replacement) would reduce BLLs in children in communities with soil concentrations similar to those identified in many neighbourhoods in Winnipeg. Based on the available information, it is also unknown if risk management measures are necessary.

A human exposure assessment is a study that examines the level of an individual's internal exposure to selected chemicals that they encounter. These types of studies are sometimes described as biomonitoring studies because they focus on quantifying exposure of humans to chemicals by measuring the amount of a chemical that is in an individual's biological fluids or tissues (*e.g.*, blood, urine, hair). These types of evaluations of exposure through biomonitoring have advantages to environmental monitoring (such as measuring chemicals in soil, air and water) as they provide information on the actual exposures experienced by people and account for exposures from all potential sources, pathways and routes that a person may encounter. The results can also be compared to national averages to determine if residents of Winnipeg have higher levels of internal exposure to lead than experienced by the majority of the Canadian population.

In addition to the collection of biological samples, such as blood for lead analysis, these studies can also include a detailed questionnaire for participants to collect information about their environment and various personal factors that may influence exposure to a given chemical such as household characteristics, occupations, diet and personal habits. The collection of environmental samples from individual households of participants can also be included as part of the study to examine the potential influence of various environmental media on levels of internal exposure. Ideally this information is collected at the time of the blood sampling. If need be, the information can also be collected after the blood sampling has been completed, with the results of the BLL sampling program informing what additional information should be collected and at what locations.

The results of each of these components of a biomonitoring study can be used to determine if children in Winnipeg have BLLs that represent a potential concern, and whether soil contamination is a significant source of exposure. This will assist in evaluating if further soil sampling is needed to characterize contamination in certain areas, and if the implementation of risk management measures is necessary.

6.2.3.1 Identification of Potential Neighbourhoods for Assessment

Based on the available information describing soil lead concentrations, current and historical sources of contamination, and sociodemographic risk factors, there is evidence to suggest that priority for further investigation of lead exposure should be given to children under the age of 7 years (and their households) within the following areas:

- **Point Douglas Area** (including both North and South Point Douglas). A notable portion of the children living in the Point Douglas area may be particularly vulnerable due to sociodemographic factors. Given the limited or absence of soil data available for areas adjacent to North Point Douglas (where the highest median soil concentration was identified), further evaluation of lead exposure in this neighbourhood may also include neighbourhoods to the west and north, including the area on the north side of the CPR tracks (*e.g.*, North End, Lord Selkirk, William Whyte, Burrows Central, Inkster-Faraday, Luxton, Mynarski, Robertson, St. Johns and St. Johns Park).

- **Inkster Area – Weston and Burrows-Keewatin**. These two neighbourhoods are of potential concern due to the presence of notable historical emission sources in the area (*i.e.*, secondary lead smelters as noted in Section 3), the identification of elevated soil concentrations at the Weston Elementary School, and the lack of available information for Burrows-Keewatin, an area that borders the Weston Shops and CPR line to the north. An alternative approach may be to complete biomonitoring and environmental sampling for Weston, and to complete soil sampling within Burrows-Keewatin to determine the need for biomonitoring in this area.

Given that soil concentrations and other factors for these neighbourhoods identify them as being of particular concern, blood lead monitoring in these areas may provide an initial indication of whether or not further study is warranted for additional areas. Based on the available soil data for the Daniel McIntyre area, this neighbourhood, as well as the adjacent neighbourhood of St. Matthews, may also represent an area that could be targeted for further assessment. This could include the addition of this area in the initial blood lead monitoring, or additional soil sampling of residential areas to supplement the existing data for parks and playgrounds to evaluate the need for biomonitoring.

Additional areas that may be considered for inclusion in a blood lead monitoring study are areas located in close proximity to the Winnipeg international airport. Given that none of these neighbourhoods were included in the Winnipeg soil investigations, and there are studies to indicate that areas in close proximity to airports may have higher soil lead concentrations relative to surrounding areas (as discussed in Section 3.2.3.2), there may be potentially unique exposure opportunities that warrant further investigation.

For comparative purposes, neighbourhoods outside of the central Winnipeg area may also be included. Potential candidates include neighbourhoods that have similar proportions of children under the age of 7 years and socioeconomic conditions that are reflective of the City of Winnipeg as a whole (*i.e.*, as a control population). It is recommended that the selected control areas include a high proportion of housing and roads constructed after 1989, after the phase-out of both leaded-paint and fuels, where lead soil contamination is anticipated to be limited. Ideally, lead concentrations in drinking water in the control areas would be consistent with those in the neighbourhoods identified as being of potential concern based on soil lead concentrations.

A description of the potential components of a biomonitoring study are provided in Appendix D.

6.3 Risk Management Options

A discussion of remediation options, personal and community intervention strategies, and public communication methods are discussed in Sections 6.3.1 to 6.3.3.

6.3.1 Remediation Options

The scale of lead contamination in urban environments presents a challenge for remediation due to the cost and disruption associated with excavation (Henry *et al*., 2015). Further, it is noted that excavation is unsustainable due to the limited number of sources of ‘clean’ soil and the potential ecological impacts of soil removal from a clean site (Henry *et al*., 2015). *In situ* approaches tend to be more practical but are not without their own challenges. A review by Scheckel *et al*. (2013) also indicated that other alternatives which reduce soil lead bioavailability may be less expensive than excavating contaminated soils and backfilling with clean soil. The use of such *in situ* agents is more-cost effective and less intrusive. Treated soils can then be covered with a green cap (soil with mulch, sod, raised garden beds) or gravel, as has been completed in the South Prescott community of West Oakland, California (Scheckel *et al*., 2013).

The use of phosphate additives is aimed at the reduction of lead bioavailability in soils by transforming the lead in soil to pyromorphite, a highly insoluble lead-phosphate mineral complex. However, measurements of the relative bioavailability of pyromorphite have not been made within the mammalian gastrointestinal tract (Alkandary, 2015). The goal of the use of phosphate treatment is to increase the soil solution and labile forms of phosphate (*e.g.*, orthophosphate) without resulting in the leaching of phosphorous to soil or water bodies (Scheckel *et al*., 2013).

Table 6-1 presents various potential soil remediation treatments and amendment processes for lead.

Table 6-1 Potential Soil Remediation Treatments and Amendments (Blaustein, 2017; Filippelli and Laidlaw, 2009; Henry *et al*., 2015; Juhasz *et al*., 2016; Scheckel *et al*., 2013; Xu *et al*., 2019).

Soil Amendment	Mechanism	Limitations of Method
Excavation	Reduction of exposure.	Potential for recontamination over time, disruption, expensive.
Physical barriers (sod, clean soil with much, raised garden beds, gravel)	Reduction of exposure.	Potential for recontamination over time, disturbance of covered areas may introduce exposure from deeper soil. Should be used in conjunction with other methods (*e.g.*, administrative controls).
Soil Treatments		
Bagasse (pulpy residue) from sugar cane, compost	Adsorption by organic matter.	pH dependent, decomposition of organic matter lowers effectiveness.
Bark saw dust or wood waste	Adsorption by organic matter.	pH dependent, decomposition of organic matter lowers effectiveness.
Bentonite	Clay mineral adsorption.	pH dependent.
Biosolids	Phosphate immobilization, organic matter adsorption, mineral oxide adsorption.	Solubility of phosphate, odour, pH dependent, decomposition of organic matter lowers effectiveness.

Table 6-1	Potential Soil Remediation Treatments and Amendments (Blaustein, 2017; Filippelli and Laidlaw, 2009; Henry *et al*., 2015; Juhasz *et al*., 2016; Scheckel *et al*., 2013; Xu *et al*., 2019).	
Soil Amendment	**Mechanism**	**Limitations of Method**
Fly ash and other coal combustion products	Organic matter adsorption, mineral oxide adsorption.	pH dependent, introduction of other contaminants from fly ash.
Hydroxyapatite (fish bone meal)	Phosphate immobilization.	Low phosphate solubility, odour, plants may be impacted by fine bone byproducts.
Iron, manganese or aluminum oxides	Mineral oxide adsorption.	pH dependent.
Lime	pH adjustment to enhance adsorption and chemical precipitation.	May impact plant grown, reversion of soil pH to natural levels over time and subsequent release of lead as a result.
Phosphoric acid	Phosphate immobilization.	Phosphate solubility can be high, significant reduction in pH resulting from acid may affect plants.
Poultry and other manure	Phosphate immobilization, organic matter adsorption.	pH dependent, phosphate solubility can be high (concerns for groundwater), odour, decomposition of organic matter lowers effectiveness, variable quality.
Rock phosphate	Phosphate immobilization.	Phosphate solubility can be low, with limited immobilization potential.
Triple super phosphate (TSP)	Phosphate immobilization.	Phosphate solubility can be high.
Xylogen (paper mill waste)	Organic matter adsorption.	pH dependent, decomposition of organic matter lowers effectiveness.
Other		
Asymmetric electrochemistry	Transports heavy metals from soil via electroosmosis and deposits them in metallic states on electrodes.	Voltage required, use of soil treatments (EDTA solution). Experimental.
Phytoremediation and phytostabilzation	Removes lead from soil through plant uptake. Phytostabilization involves the sequestration, dilution and reduction of bioavailability.	Limited efficiency of uptake by various plants and plant parts. May require use with other methods. Time for improvement is long.

Henry *et al*. (2015) acknowledge that there is uncertainty regarding the extent and duration of effectiveness associated with the use of phosphate amendments in different soil types with varying levels of contamination. The studies completed to date for phosphate amendments have typically involved highly contaminated soils over relatively short durations of time (months to a year) (Henry *et al*., 2015). For the treatment to be effective in the immobilization of lead, bench tests of the applicable soil with various phosphate materials were noted to be one of the best recommendations to determine an appropriate material for amending soils (Scheckel *et al*., 2013).

Soil moisture, temperature and pH can influence the speciation and availability of phosphorous within soils (Scheckel *et al*., 2013). Scheckel *et al*. (2013) concluded that there are several factors that may limit the conversion of lead to pyromorphite:

- High retention of soil lead to limit the extent of the reaction with phosphate;
- Limited phosphate availability in the amendment or the reaction of available phosphate with other soil components (oxides, organic matter);
- Poor characterisation of the soil matrix before the addition of phosphate amendment;
- Soil pH that is non-optimum and results in a rate-limiting release of lead and phosphate in soil to form pyromorphite;
- High organic matter content, that may inhibit pyromorphite formation;
- Soil moisture content; and,
- The use of phosphate treatment for the immobilisation of lead concentrations greater than 4,000 µg/g may not be feasible, and removal is the recommended option in those cases (Scheckel *et al*., 2013).

The type of remediation method that would be of use to different sites within the various Winnipeg neighbourhoods varies with:

- Depth and horizontal extent of lead contamination in soil;
- Land use type (residential, parks, school);
- Data availability;
- Soil characteristics (*e.g.*, organic matter, pH); and,
- Potential future up-keep requirements (*e.g*. phosphate treatments, preservation of soil amendments or land-covers).

At this time, due to the number of data gaps and the wide range in soil lead concentrations in the studied neighbourhoods of Winnipeg, the identification of suitable remediation options is difficult.

6.3.1.1 Weston Elementary School

Advice has been requested on the Weston school playground as the school represents a defined area in which soil lead concentrations are well characterized. Currently, access to the playground area and sod-covered sports field are restricted for students and the public by fencing. As the school represents a defined area in which soil lead concentrations have been fairly well characterized, specific risk management options for this site may be practical.

In 1980 and 1981, concentrations of lead were identified to exceed the then applicable guideline of 2,600 µg/g in particulates from the paved play area at the north side of the Weston Elementary School, with an average concentration of 4,850 µg/g (Jones, 1985). In response, a dry vacuuming procedure was used to remove approximately 1.0 tonne of debris in 1981. Ongoing monitoring in 1982 and 1983 identified that lead concentrations in debris once again exceeded the guideline. Dry vacuuming removed an additional 1.36 tonnes of debris in 1983 (Jones, 1985). Given that deteriorating lead paint was suspected to be contributing to the elevated concentrations of lead in debris at the Weston Elementary School, all painted surfaces on the north and west sides of the school were scraped and repainted in the summer of 1984. This was followed by the removal of the paved ground surfaces adjacent to Logan Avenue at the front of the school and along Quelch Street on the west side of the property. New soil, sod, trees, and shrubs were added to these areas. Despite these efforts, lead concentrations in excess of the CCME guideline (140 µg/g) continue to exist.

Soil lead concentrations in the Weston Elementary sports field as sampled by Manitoba (2010) were found to range from 89 to 1,130 µg/g (samples collected at a depth of up to 5 cm), with an average concentration of 398 µg/g. Samples of dust/soil and mixed materials on hard surfaces near the school and sod (not from sports field) collected from a depth of up to 2.5 cm all have been found to have lead concentrations less than the CCME guideline of 140 µg/g. Sampling locations from the 2010 report are presented as the larger dots within Figure 6-2.

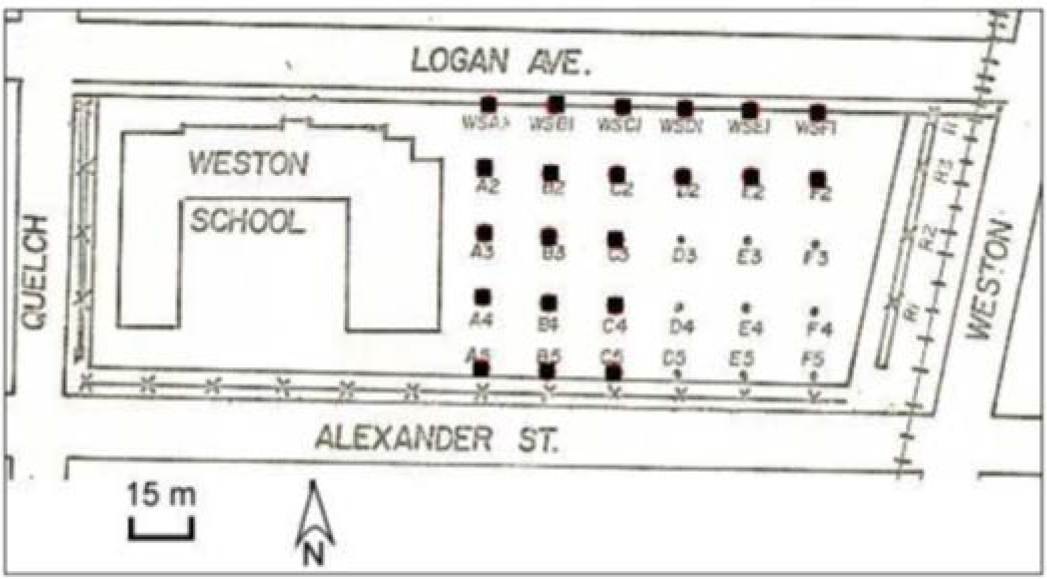


Figure 6-2 Summary of sampling locations at the Weston Elementary School as part of the 2007-2008 Provincial investigation (Manitoba Conservation, 2010).

The 2018 Provincial investigation included 22 soil and sod samples collected from the school yard; however, these samples were collected from a depth of 0-7.5 cm and may not be representative of lead concentrations in the near surface soils which children may be exposed to on a regular basis. Concentrations of lead in the school yard samples ranged from 96.3 to 446 µg/g, with an average of 216 µg/g. Overall, 18 of the 22 samples contained concentrations of lead that exceeded the CCME guideline of 140 µg/g. Additional schools and playgrounds (or Tot Lots) within the Weston area have also been included in sampling studies. In general, lead concentrations in these samples have been below the CCME guideline of 140 µg/g.

The sports field appears to be well covered by grass with limited or no exposed soils. As a result, there is uncertainty regarding the potential opportunities for exposure to underlying impacted soils. Potential options for further investigation and/or risk management measures for the Weston school yard and sports field include:

- The collection of surface soil and sod samples at a depth of 0-2.5 cm to characterize current surface soil conditions. Any visibly exposed areas of soil or aggregate should be sampled;
- Measures should be taken to minimize the generation of dust or exposure to underlying soils during landscaping maintenance (*e.g.*, aeration, leaf blowing);
- Dust-generating sand or gravel in the playground area could be replaced with a soil barrier or solid rubberized playground surface material. If a barrier/rubber material are not installed, consideration should be given to regular replacement of sand/gravel over time. Wipe samples can be collected from hard surfaces (including playground equipment) an analyzed for lead content (before and after the implementation of any mitigation measures);
- The replacement of grass with artificial turf for the sports field could be considered. This will act as a complete barrier to any underlying impacted soils. Dust control measures must be implemented during any excavation and installation procedures to reduce the re-suspension of impacted materials which may be re-deposited on the new artificial surfaces or adjacent properties;
- Promote hand washing and hygiene at the school (as well as to potential park users, including area day cares and day homes) through an awareness campaign, and the distribution of kits to parents and caregivers regarding handwashing and lead awareness;
- Site-specific remediation (*in situ* or *ex-situ*) of lead. Soil removal or treatment may represent a direct and effective means to address the identified soil contamination. Given the relatively limited size of the impacted area, soil removal may be a feasible option, however, it must be recognized that there is the potential for the re-contamination of any treated land or clean-fill over time if elevated soil concentrations or other sources of lead continue to exist in the surrounding neighbourhood.

Several of the above listed risk-mitigation measures could also be proactively taken for the other schools, playground and recreational areas within the Weston neighbourhood on a case-by-case basis with the overall goal of reducing the potential for soil and outdoor dust exposure to young children. Given the limited sampling for other parts of the Weston area, there is the potential that any actions taken at the school would be potentially negated by re-suspended soils from other parts of the neighbourhood.

6.3.2 Personal and Community Intervention Strategies

An overview of blood lead intervention strategies applied by various jurisdictions in Canada, the US and internationally were outlined in Section 4.2.4 of this report. A number of case studies for communities with lead exposure concerns were described in Section 4.2.5. In Section 4.2.6, a summary of the effectiveness of various interventions was discussed based on published literature. A brief discussion of some of these interventions is provided below and summarized in Table 6-2.

Exposure to lead may occur *via* consumption of food and drinking water, direct contact with lead impacted soils, inhalation of particulates, and exposure to consumer products. In Winnipeg, there is information to indicate that most homes are not impacted by lead in drinking water due to low concentrations in the City's source water and the implementation of lead control programs (City of Winnipeg, 2019b). Although lead in drinking water is not identified to be a significant source of lead exposure to the majority of the population in Winnipeg, there are areas where the presence of leaded plumbing may represent a potential concern (refer to Figure 3-7 in Section 3.2.5).

Elevated concentrations of lead in urban soils have been identified as a significant source of lead exposure, either through direct incidental ingestion of outdoor soil or through its contribution to lead in indoor dust. Several agencies and jurisdictions have identified preventative measures and recommendations for reducing exposure to lead in soil. The recommendations are often behavioural strategies for the general public and can be categorised into three (3) major classifications: 1) house cleaning for dust control, 2) hygiene and personal care, and, 3) diet (NZ MOH, 2012):

- Dust Control: Good housekeeping recommendations often include using wet-mopping techniques, vacuuming with high efficiency particulate air (HEPA) filters, regularly cleaning windowsills, and other cleaning efforts.

- Hygiene and Personal Care: Hygiene and personal care suggestions often include washing hands frequently, keeping children and pets away from bare soil, and using door mats at entrances to homes. These recommendations aim to decrease exposure to lead through the ingestion pathway.

- Nutritional Status: Nutritional status, among many other factors (*e.g.*, age, health, particle size, solubility, route of exposure, etc.) may impact lead absorption. Dietary deficiencies, specifically of iron, calcium and vitamin C have been linked to increased lead absorption following exposure (ATSDR, 2019). Changes in diet have been recommended by several health agencies. Specifically, healthy low-fat diets consisting of foods that are rich in iron, calcium and vitamin C are recommended as they are noted to play a role in reducing lead absorption (US EPA, 2001). Examples of iron-rich foods include iron-fortified cereals, dried fruit such as raisins and prunes, lean red meats, fish, and chicken (US EPA, 2001). Vitamin C improves iron absorption and helps to reduce lead absorption; sources of high vitamin C include oranges, grapefruit, tomatoes and green peppers. It is important to note, however, that there are currently very few conclusive studies and little evidence to suggest that changes to diet would considerably lower children's BLL (Kordas, 2017).

Overall, general recommendations from various agencies such as the Center for Disease Control, US EPA, New Zealand Ministry of Health include the following:

- Limit the amount of soil brought into homes by taking off outerwear (*e.g.*, coats, shoes, etc.);
- Use door mats or place washable rugs at home entries;
- Clean your house often to reduce dust build-up (*e.g.*, use HEPA air vacuums when possible, clean window frames and sills often);
- Wash hands frequently, especially children;
- Bathe pets frequently;
- Avoid eating or drinking while working outdoors in the yard/garden;
- Damping soils with water before you garden to limit the amount of dust you inhale;
- Avoid working or playing in the yard on windy days when dust may be stirred up;
- Keep children/pets away from bare soil areas and aim to cover bare soil;

- Have children play in grassy areas or a sandbox that can be covered;
- Avoid eating root vegetables (*e.g.*, carrots, beets) and leafy greens (*e.g.*, lettuce, herbs) that have been in direct contact with contaminated soil;
- Thoroughly wash other types of vegetables or fruits (*e.g.*, tomatoes, cucumbers, eggplants, peas) that have been grown in direct contact with contaminated soil;
- Soak garden produce in cool water and rinse until water runs clear;
- Scrub vegetables well before eating with a vegetable-cleaning brush to remove dust and dirt;
- Wash berry fruits (*e.g.*, strawberries, blackberries) and remove the tops of the berries where the stem and leaves attach;
- Clean your hands, cutting boards, and other kitchen tools with hot soapy water before and after handling garden produce. Rinse well;
- Grow vegetables in planter beds using store-bought soil and always wash garden produce;
- Regularly check the exterior of homes, fences, etc. for deteriorating lead-based paint that may contaminate soil;
- Hire a certified lead professional to remove old lead-containing paint;
- Use trisodium phosphate detergent as an effective measure for dust suppression;
- Diet may protect the body from absorbing lead. Iron and calcium deficiency strongly influence lead absorption and as such, eating calcium-rich and iron-rich foods is recommended;
- Have frequent small meals, rather than fewer large meals. Lead has been shown to be absorbed much better on an empty stomach;
- Keep play areas clean and wash bottles, pacifiers, toys, stuffed animals etc. regularly;
- Keep windows closed on windy days to reduce lead dust to be blown indoors;
- Add fences and vegetation help to reduce wind from carrying contaminated soils;
- Garden produce that do not have removable peels (*e.g.*, tomatoes and carrots) should be rinsed with a mild vinegar. Remove outer leaves of garden produce that do have removable exteriors (*e.g.*, lettuce, cabbage);
- Children should play away from painted play-structures that may contain lead; and,
- Add lime to soil as recommended by soil test (soil pH of 6.5 to 7 will minimize lead availability).

Links to the websites where information from these and other agencies can be found are provided in Appendix E.

A number of community-based risk mitigation activities were completed in Flin Flon, Manitoba, in conjunction with environmental and biological monitoring programs (Intrinsik, 2012). Several of these activities may be of interest to regulators and risk managers for the City of Winnipeg. These activities included:

- Factsheets regarding lead and lead-exposure, lead-based paint, and the importance of handwashing were made available on-line, at community events, and at various public buildings.
- A website was launched in 2011 (after the first biomonitoring program in 2009 but before the second program in 2012). This website was the hub for all program information, updates, and resources, which were also shared *via* various social media outlets.
- Community leaders from Flin Flon obtained training on developing, executing and building support for grassroots, community-driven initiatives.

- A hand-washing education program was launched at various community events aimed at children under the age of six (6). A hand washing “super hero”, Mighty Bubble, built a name for himself by appearing at these events and his character was incorporated into a handwashing “toolkit” that was distributed to all kindergarten to grade 2 students in Flin Flon/Creighton, as well as to all children at public daycare centres in the community. Toolkits containing resources for parents and caregivers were distributed to children after participating in workshops led by the regional health authority, as well as to children participating in programming at the Aboriginal Friendship Centre. A music video with the Mighty Bubble character was developed for young children with support from local health authorities and community health care workers.
- Lead test kits certified by the US EPA were made available to the community of Flin Flon at no charge at certain hardware stores, and also at special events within the community or as part of a door-knocking awareness campaign.
- A HEPA vacuum was purchased and made available by anyone at no charge to members of the community or contractors to help ensure adequate clean-up of lead dust generated by renovation projects.

Table 6-2 Summary of Intervention Case Studies and Literature-Based Approaches for Lead Management

Case Study or Jurisdictions	Interventions Applied	Notes
Flin Flon, MB	Biomonitoring and household environmental sampling programs Source reductions: Progressive remediation and re-vegetation program Paving of roads and improvements to materials Operational changes and eventual closure of smelter Outreach: Public communication and handwashing campaigns, individual interventions when necessary to reduce exposures Individual interventions when necessary to reduce exposures	Environmental factors found to be poor predictors of child BLL, other than that the closure of the smelter contributed to the reduction of BLL in the community. Limited impact of handwashing and hygiene campaign. Removal of source (smelter closure) had the greatest effect on BLLs.
Trail, BC	Biomonitoring and household environmental sampling programs Source reductions: Technological improvements at the smelter with improved dust control Emission reductions Site-specific remediation in areas where extensive sampling has found elevated concentrations Dust control measures on roadways and alleys, unpaved areas Soil replacement plans Outreach: Lead-safe home renovation plans Public communication and handwashing campaigns Individual interventions when necessary to reduce exposures	Additional soil testing and site-specific remediation on-going at properties that are accessible to children under the age of 12 years.
Hamilton, ON	Recommended actions included: Free inspection and replacement of water service lines Provision of on-tap water filters to low-income households Development of an environmental lead awareness program targeted at high risk groups	It is not clear what actions have been taken to date.
Montreal, QC	Biomonitoring and tap-water sampling Recommended actions included: Use of pitcher water filtration systems or tap-water filters in affected areas Use of bottled water (particularly for infants) Allowing water to run freely before use Limiting water consumption to cold, not warm or hot water Regular cleaning of screens and aerators.	It is not clear what actions have been taken to date.
St. John's	Biomonitoring and environmental sampling No recommendations or intervention information available for comparison	
Butte, Montana	Biomonitoring and environmental sampling Source reductions: Clean-up and capping of exposed soils, mine waste dumps and overburden piles in neighbourhoods that were accessible to children Impacted areas remediated into recreational parks, memorial and historic sites Stormwater management practices improved to reduce impacts on area groundwater Contaminated sediments removed in nearby creek affected by mining waste	

Table 6-2 Summary of Intervention Case Studies and Literature-Based Approaches for Lead Management

Case Study or Jurisdictions	Interventions Applied	Notes
	Comprehensive testing and clean-up plan for affected residences Outreach: Community-led land re-use and development plans	
Herculaneum, MO	Source reduction: Reduction of smelter emissions Relocation of high-risk families Soil remediation Purchase of impacted properties by facility owner. Outreach: Educational programming	Limited information is available for this site.
Broken Hill, AUS	Biomonitoring and environmental sampling Source reduction: Capping of exposed mine tailings and impacted soils Remediation of public land Household remediation and renovation programs Outreach: Public education and health promotion Individual case management of children	Lead-emissions from this facility are on-going, as are remediation efforts.
Point Pirie, AUS	Biomonitoring and environmental sampling Source reduction: Site-specific remediation of heavily impacted residential areas and soil replacement Removal of lead paint Dust mitigation (indoor and outdoor) Occupational approaches to reduce workers from brining lead home from smelter Daily cleaning of high-use community facilities Replacement of bark chips in playgrounds Mulching of exposed soils and seeds Improved cleaning in high-risk areas Proposed modifications to smelter emission controls Outreach: Family education and in-home support	Smelter is an on-going lead emission source in the area.
Approaches Evaluated in Literature		
Campbell *et al*. (2003)	One-time professional cleaning found to reduce dust levels in homes with elevated BLLs for a short duration of time.	
Cluett *et al*. (2019)	Lead abatement activities in homes were observed to be beneficial in children with BLLs between 5 to 9 µg/dL.	
Dugbatey *et al*. (2005)	No significant effect observed on BLLs in infants based on educational programs (hygiene, cleaning, property maintenance, nutrition) aimed at low-income inner-city pregnant women.	
Ettinger *et al*. (2002)	Significant reductions in lead concentrations in house dust after professional cleaning in children with BLLs above 20 µg/dL.	

Table 6-2 Summary of Intervention Case Studies and Literature-Based Approaches for Lead Management

Case Study or Jurisdictions	Interventions Applied	Notes
Haynes *et al*. (2002)	Low-cost interventions were found to be somewhat effective in reducing BLLs in children with BLLs above 15 µg/dL but were less effective in lowering BLLs at levels below 15 µg/dL. Unless the source of house-dust contamination is identified and removed, home-based approaches are not likely to have an effect on BLL.	
Kegler and Malcoe (2004)	No effect of educational interventions observed on BLLs in children living near mining area.	
Lanphear *et al*. (2000)	No significant changes observed in BLLs of children whose families received training on lead poisoning preventions and cleaning (along with equipment and cleaning supplies being made available).	
Nussbaumer-Striet *et al*. (2016)	No significant benefit identified in association with household dust control or educational interventions. Determined that the US household dust standards at the time (have since been updated in 2019) were not adequately protective. Noted that information is insufficient to draw conclusions as to the effectiveness of soil abatement programs on childhood BLL.	
Rhoads *et al*. (1999)	Children in homes cleaned more than 20-times per year by professional services had reduced BLLs.	
Shao *et al*. (2017)	Study included several BLL interventions at the regulatory level as well as in-home lead paint abatement in low-income housing areas. Concluded that once BLLs reach a certain point, aggressive abatement practices may have minimal benefit.	
Taylor *et al*. (2011)	Evaluated various educational-based interventions, including personal hygiene, child mouthing behaviours, cleaning, household dust management. Difficult to attribute one type of intervention as being effective over another. Generally, interventions are found to be ineffective but have had mixed results. Most effective BLL reduction strategies involve reduction of point source and fugitive emissions from lead emission sources.	
Yeoh *et al*. (2012)	No significant difference in effectiveness of reducing BLLs identified in systematic review of literature for educational interventions. Benefit of soil abatement (removal and replacement) could not clearly be distinguished in studies where more than one intervention applied.	

6.3.3 Blood Lead Monitoring and Reporting

In Section 4.2.4.1 of this report, various approaches used by regulatory agencies in Canada for blood lead intervention were evaluated. No information regarding mandatory blood lead reporting or tracking was identified for any province or territory with the exception of Quebec. In Quebec, lead exposure is considered to be a reportable disease. British Columbia is considering making the reporting of all blood lead analysis subject to mandatory reporting to Medical Officers of Health (BC CDC, 2014).

In the United States, it has been recommended that all children be tested for blood lead at least once and be subject to additional monitoring and intervention when necessary (ACCLP, 2012). Various US States have different approaches for the evaluation of blood lead. In California, all health care service plans that cover hospital, medical or surgical expenses must also cover blood lead screening for children at risk of lead poising (Leg Cal, 2019a; CDTSC, 2019). In the States of Alaska, Maine, and Michigan, all children covered by Medicaid must be tested for lead exposure between the ages of 1 or 2 years (CCLPPCC, 2007; Gomez *et al*., 2019). Public health law and regulations in New York State require that all children are tested for lead at ages 1 and 2 years (NYSDOH, 2019). Washington State recommends that all health care providers educate parents of children between the ages of 6 months and 6 years regarding lead exposure, and also complete blood lead testing between the ages of 1 and 2 years (WSDOH, 2018).

In comparison to other Canadian provinces and territories, Manitoba seems to be consistent with the other areas (with the exception of Quebec and perhaps British Columbia) with respect to blood lead management. However, some States in the US have developed more comprehensive systems for the screening of children for lead exposures.

A reporting system that ensures that any children in the province who are tested by their family physician or other public health personnel are tracked and receive any necessary follow-up may assist public health officials in identifying clusters of children who are potentially being adversely affected by lead.

6.3.4 Public Communication Methods

A combination of communications strategies may be the most effective approach for delivering a message to a community or general population. This may include direct interpersonal channels (*e.g.*, friend to friend, doctor to patient, teacher to class), and indirect mediated channels such as social media, the newspaper, radio and television (PHO, 2012).

Communication methods may be selected based on the target audiences (*e.g.*, schools, general community), cost and effectiveness. Methods of communication may include:

- Press releases
- Letters and fliers
- Factsheets
- Dedicated website
- Staff newsletters
- Emails

- Social media
- Notices to school boards
- Medical clinics

The CDC's social media tool kit provides guidance on determining the best channels to utilize based on messaging objectives. Figure 6-3 presents various social media platforms that can be utilized in an outreach strategy.

Dissemination → Engagement

Tools	Resources: Time/Staff Low	Time/Staff Moderate	Time/Staff High	Cost Low	Cost Moderate	Cost High
Buttons/Badges	✓			✓		
Content Syndication		✓		✓		
RSS Feeds	✓			✓		
Image Sharing	✓			✓		
Podcast Posting	✓			✓		
Online Video Sharing	✓			✓		
Widgets[1,2]	✓			✓		
eCards[3]	✓			✓		
Micro-blogs		✓		✓		
Podcast Creation		✓			✓	
Online Video Production		✓			✓	
Blogs		✓			✓	
Mobile Technologies/ Texting		✓				✓
Virtual Worlds		✓				✓
Social Networks			✓	✓		

[1] Indicates the posting of a widget, not production.
[2] Although the majority of widgets feature embedded content, some may contain an interactive component such as a quiz or a calculator.
[3] Indicates the sending of an eCard, not production.

Figure 6-3 Examples of Communication Tools (CDC, 2011).

Sullivan and Green (2016) identified the importance of providing consistent, accurate and comprehensive information on risks associated with lead exposure. The study compared public health education materials for three (3) Australian cities (*i.e*., Broken Hill, Mount Isa, and Port Pirie) that have active lead mines and/or smelters. The study found inconsistencies with strategies to reduce exposure to lead and concluded that education materials need to clearly state health risks associated with lead for various vulnerable and marginalized populations. Sullivan and Green (2016) recommended that a national and harmonized approach to health education on lead, led by the National Health and Medical Research Council, be taken. This approach should include health education for lead which integrates community participation, pays attention to disparities among Aboriginal communities, and follows national and international best practices.

7.0 SUMMARY OF UNCERTAINTIES AND LIMITATIONS

The identification of neighbourhoods as being of potential concern was based on a limited number of samples which may not accurately characterize soil lead concentrations throughout these areas. Additionally, other neighbourhoods may also contain lead concentrations occurring at a frequency and magnitude that represent a potential concern which have not been identified by the available data. Significant gaps in the soil data are apparent in the areas immediately surrounding the railway line, particularly on the north side between McPhillips and Main Streets, to the north of Dufferin and Dufferin Industrial. This area includes a large portion of the Point Douglas Community Health Area and an area of the City known as the 'north end'. While data for North Point Douglas, Dufferin, and Dufferin industrial, and a few data points for South Point Douglas are available, there is an overall lack of coverage.

The Weston area data set is also affected by the lack of residential samples. All available data are for samples collected from the elementary school or sports field, and a few playgrounds. While these are of relevance to school-aged children, they do not necessarily capture the exposures that children under the age of 6 years may be receiving at home or in childcare. The data is clustered and does not provide full coverage of the neighbourhood as a whole. Further, numerous samples for Weston were collected at a depth of 0-7.5 cm rather than 5 cm or less.

There are some notable data gaps for the neighbourhoods within the Downtown area of Winnipeg. All of the available information for Daniel McIntyre (also considered be part of the Downtown Community Health area) is clustered within area parks, without any coverage of residential areas. Most of the soil data available for the neighbourhood of Centennial was collected from the Dufferin Elementary School and did not include areas more representative of residential exposures to which young children could be exposed. Several samples were collected in Wolseley/Minto and Sargent Park from schools, community centres and residential boulevards, however, no samples have been collected from residential properties in these areas either. No residential area data are available for the other areas that fall within the Downtown Community Health Area – Central Park, Assiniboine, West Alexander, West Broadway and Spence or St. Matthews (located to the south). While it is acknowledged that this area is less residential than some of the other neighbourhoods evaluated, the 2016 census data indicates that there are children residing in these areas.

The data set for the neighbourhood of St. Boniface is the largest out of all of the neighbourhoods evaluated in this assessment. The St. Boniface data from the investigations conducted by both the Province and the University of Manitoba are focused on soil samples from a depth of 0-7.5 or 0-10 cm, rather than less than 5 cm as recommended for the health assessment of lead. Soil sample locations were inconsistent, with many of the St. Boniface samples collected from gardens. It is likely that garden soils are amended to some extent with soils obtained from other areas (e.g., topsoil, manure, compost, mulch, etc.) and as a result, there is uncertainty regarding the use of these samples to represent soil lead concentrations on a given property.

There is a large degree of uncertainty in utilizing relationships between soil lead and blood lead identified from other studies or estimated using the IEUBK model to predict BLLs in children in a neighbourhood of interest. The assumptions and algorithms used within the IEUBK model are designed to predict the likely distribution of BLLs in young children. Use of the IEUBK model for a community-based assessment has limitations in that it assumes that all children within a given population will be exposed to homogenous levels of lead under a similar exposure scenario. In reality, there may be significant variability in the lead concentrations in media such as indoor dust and backyard soil across properties within any given neighbourhood. The use of empirical results to provide an indication of BLLs based on soil concentrations also has several limitations and uncertainties given that there are inherent assumptions regarding similarities in soil lead bioaccessibility, characteristics of the exposed population, and non soil-related exposures.

The current assessment addressed potential risks associated with concentrations of lead measured in soil in inner city Winnipeg but did not evaluate or provide recommendations for methods to prevent future and ongoing contamination. New and revised policies related to sources of lead, industrial setbacks, emissions and air quality objectives, and licensing approvals may also result in improvements related to lead in soil. Such decisions should be made in consultation and partnership with municipalities, communities and industry.

8.0 RECOMMENDATIONS

Based on the findings of the work completed in Tasks 1 to 5, recommendations are provided for consideration by the Province related to risk communication, risk management, and further investigation of potential human health risks associated with lead in soils within the City of Winnipeg.

Recommendation 1: Community Outreach and Education.

It is recommended that the Province, in collaboration with key stakeholders (including but not limited to the City of Winnipeg), develop an overall lead awareness communications program. This program should develop opportunities to communicate the potential for lead exposure, the potential health hazards in Winnipeg, and options for reducing exposure to lead. A central repository for information should be maintained on a dedicated website with social media linkages. All reports, presentations, factsheets, status updates, and press releases could be shared on such a website, including the final version of this assessment as well as all historical reports characterizing lead in soils in Winnipeg. This may be an expansion of the existing "*2018 Winnipeg Lead in Soil Survey*" page (https://www.gov.mb.ca/health/publichealth/environmentalhealth/wlss.html) which already includes links to numerous fact sheets and historical reports. Practical approaches for reducing exposure to lead are already provided on this website, focusing on all potential sources including soil, home gardens, drinking water, paint, and hobbies. This website and related social media platforms could also provide an opportunity for residents to submit written questions or concerns to be addressed by a public health representative in Winnipeg (in addition to the current opportunity to call a health care provider or Health Link representative *via* the phone numbers provided). The website should be updated on a regular basis and provide an opportunity for health officials to address new and emerging concerns related to lead circulating in the news and on social media (*e.g.*, new studies on lead in drinking water throughout Canada, the release of the findings the City of Winnipeg's drinking water study).

<u>Factsheets</u>

The Province has existing factsheets regarding general lead exposure and risks, soil lead exposure and risk to Winnipeg residents, as well as exposures related specifically to gardening. As part of a city-wide communications strategy that could begin at any time, this information should be updated and shared widely. Based on the technical aspects of the literature reviewed within this report, suggested edits are provided below.

For the general lead factsheet, it is suggested that additional information and recommendations include:

- Covering bare, unamended soils on residential properties, including gardens and lawns with inconsistent grass cover. This may include the addition of new sod to lawns, or mulch, rocks, or other materials to gardens.
- The provision of preferred areas for children to play (*e.g.*, raised sandbox, play structures).
- Thorough and regular cleaning of toys and pacifiers used by children.
- Use of doormats at house entrances and consistent removal of outdoor footwear at entranceways.

- Regular wet mopping of floors and the use of vacuums with HEPA filters.
- General information regarding home gardening (beyond the link provided to ensure that people read the necessary information).

For the gardening factsheet, it is suggested that additional information and recommendations include:

- Limit or prevent children from entering gardens if contaminant levels are unknown.
- If contaminant levels are unknown, or the area is known to have elevated lead concentrations in soil, reduce or eliminate practices that bring deeper soils to surface such as aeration or tilling or those that can re-distribute dusts (*e.g.*, leaf-blowing).
- If unsure or concerned regarding garden food exposures, consider planting ornamental plants and ground coverings.
- If soil pH is found to be below 6.5 or above 7.5, apply soil treatments to adjust soil to neutral pH (*e.g.*, between 6.5 and 7.5).

Training for Daycares, Community Centres, Preschools, Schools and Parents Regarding Lead Exposure Prevention

The lead awareness campaign could include training on hand washing and hygiene, including the distribution of kits to parents and caregivers. This program could be similar to that created for Flin Flon where a hand washing "super hero", *Mighty Bubble*, appeared at events and his character was incorporated into a handwashing "toolkit" that was distributed to all kindergarten to grade 2 students, as well as to all children at public daycare centres in the community. Similar toolkits containing resources for parents and caregivers can be distributed to children after participating in workshops led by community health care workers.

Recommendation 2: Biomonitoring and Paired Environmental Sampling Study

Based on the results of the literature review and predictive blood lead modelling, a number of neighbourhoods were identified as having soil lead concentrations that may be associated with elevated risks to residents. Given these findings and the uncertainties related to theoretical risk estimates and the limited soil sampling data for residential properties, it is recommended that a biomonitoring study is completed with paired environmental sampling (of soil, drinking water, interior paint, and dust) for residences with children under the age of 7 years with the objective of measuring actual levels of lead exposure. This will help determine if exposures experienced by young children represent a potential health concern. Such a study could be part of a larger lead management and communication strategy by the Province in partnership with other stakeholders (*e.g.*, the City of Winnipeg) to address overall lead exposure (*e.g.*, including drinking water). This study should be within the identified priority areas of:

1. **Point Douglas** (specifically North Point Douglas, South Point Douglas, and neighbourhoods to the west and north that have not been sampled for lead to date). This area has been identified as having elevated soil lead concentrations above what has been reported in urban areas where lead has been identified as a potential concern in other parts of the world. The soil measurements to date have been focused in a small area of Point Douglas. Using the IEUBK model, the predicted geometric mean BLL for the neighbourhood of North Point Douglas was 4.7 µg/dL. A significant proportion of soil

samples collected from residential boulevards in this area contained lead concentrations that exceeded values derived to be protective of a BLL of 2 µg/dL. Further, due to the proportion of young children in this neighbourhood and the low socioeconomic and health status of the area, biomonitoring and environmental sampling in this area should be given particular priority.

2. **Inkster** (specifically Weston, as well as Burrows Keewatin which has not been sampled to date). This area is highlighted due to its proximity to several historical emission sources and the identification of elevated soil lead concentrations at Weston Elementary School. Using the IEUBK model, the predicted geometric mean BLL for the neighbourhood of Weston was 2.6 µg/dL. These results are based on soil samples collected from the Weston School which has undergone multiple rounds of remediation. Higher concentrations may exist on residential properties in the surrounding area. An alternative approach may be to complete biomonitoring and environmental sampling for Weston to characterize exposure and identify the need for risk-mitigation measures, and to complete only soil sampling within Burrows-Keewatin to determine the need for any future biomonitoring in this area.

The areas listed above for proposed future study include neighbourhoods located in proximity to major roadways, current or historical industrial emission sources, and areas with older housing that may have lead paint and lead-containing plumbing and fixtures. It may also be of value to extend the biomonitoring study into the Downtown area (*e.g*., Daniel McIntyre) given the limited extent of sampling coverage in this area.

The aim of the biomonitoring study is to measure the actual levels of exposure experienced by children in the selected neighbourhoods of potential concern. In the event that the study identifies children with elevated BLLs that represent a health concern, appropriate risk mitigation strategies can be developed on an individual level with the assistance of medical and public health personnel, to reduce their overall exposure to lead. The environmental sampling of the households of participating children included in a biomonitoring study is intended to capture individual exposure hazards, as well as to provide information regarding sources of lead exposure on a residence-to-residence basis such that the need for community-wide action can be more clearly evaluated.

The findings of the biomonitoring and environmental sampling may reveal the need for additional study in other areas of Winnipeg. It is also suggested that one or two neighbourhoods from outside the central core area of Winnipeg that are of reflective of the socioeconomic and health status of the City of Winnipeg as a whole are included as a control group for comparison.

Recommendation 3: Weston School and Playgrounds.

It has been requested that a specific course of action be recommended for the Weston Elementary School based on the extent of sampling completed to date. Despite the elimination of the primary historical sources of lead emissions (*i.e.*, the Canadian Bronze smelter and leaded fuels), and the completion of a number of remediation activities, elevated concentrations of lead continue to be identified in soils on this property. Ongoing contamination of soils and sod may be related to the re-distribution of particulates from adjacent properties. Elevated concentrations of lead were identified in the school yard in the most recent Provincial survey at a frequency and magnitude that warrants further investigation and potential risk management. Given that the winter 2019/2020 season is commencing which will restrict access to impacted soils due to frozen ground and snow cover, the implementation of immediate risk management measures is not considered to be necessary. However, it is recommended that students, parents, and staff are made aware of the potential concerns related to lead in soils on the school grounds and are provided with an overview of the potential future actions that are being considered by the Province.

In order of priority, recommended actions for the Weston school yard and sports field include:

- Promote hand washing and hygiene at the school (as well as to potential park users, including area day cares and day homes) through an awareness campaign, and the distribution of kits to parents and caregivers regarding handwashing and lead awareness;
- The collection of surface soil and sod samples following the spring thaw at a depth of 0-2.5 cm to characterize current surface soil conditions. Any visibly exposed areas of soil or aggregate should be sampled;
- Before the time of the first period of lawn maintenance in the spring/summer, the maintenance staff at the school (and also other parks in the Weston area) should be instructed to take measures to minimize the generation of dust or exposure to underlying soils during landscaping maintenance (*e.g.*, aeration, leaf blowing);
- Replacement of dust-generating sand or gravel in the playground area with a soil barrier or solid rubberized playground surface material. If a barrier/rubber material are not installed, consideration should be given to regular replacement of sand/gravel over time. Wipe samples can be collected from hard surfaces (including playground equipment) an analyzed for lead content (before and after the implementation of any mitigation measures) on an annual or seasonal basis;
- Exposed soil surfaces should be covered in mulch, sod, or groundcover to prevent direct access to soils and the generation of dust; and,
- Dependent on the findings of the supplemental sampling of soil, sod, and hard surfaces, the replacement of grass with artificial turf for the sports field could be considered. This will act as a complete barrier to any underlying impacted soils. Dust control measures must be implemented during any excavation and installation procedures to reduce the re-suspension of impacted materials which may be re-deposited on the new artificial surfaces or adjacent properties. If installed, the turf should be cleaned and maintained as per the manufacturer's instructions, with any solid or liquid waste from the turf contained and disposed of appropriately off-site.

Several of the above listed risk-mitigation measures could also be proactively taken for the other schools, playgrounds, and recreational areas within the Weston neighbourhood on a case-by-case basis with the overall aim of reducing the potential for soil and outdoor dust exposure for young children.

Recommendation 4: Blood Lead Reporting and Monitoring.

Currently, elevated blood lead is not considered to be a reportable disease in Manitoba, and in the event that a family doctor requests that a child be tested for lead exposure, there is no tracking of this at a public health level. A reporting system that ensures that any children in the province who are tested by their family physician or other public health personnel are tracked and receive any necessary follow-up may assist public health officials in identifying clusters of children who are potentially being adversely affected by lead.

9.0 CLOSURE

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APPENDIX A

Database Searches for Possible Emission Sources

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A-1. INTRODUCTION

This Appendix is intended to supplement the information provided within Section 3 of the main report.

A-1.1 National Pollutant Release Inventory (NPRI) Search

The National Pollutant Release Inventory (NPRI) publicly accessible database was utilized to identify current and historical facilities that are releasing lead or have released lead in large quantities to the environment. Reporting to this database is required by Environment and Climate Change Canada (ECCC) under *Canadian Environmental Protection Act, 1999* (CEPA) (ECCC, 2016). The online query tool was utilized to search for specific information on lead releases by facilities reported to the NPRI by filtering by substance, reporting year, and location (ECCC, 2018). Table A - 1 presents the search query inputted in the online query tool.

Table A - 1 Search Query for NPRI Inventory

Search information	Inputted Search Criteria
Reporting Year	1994 to 2017
Substance (First Query); CAS Number	Lead (and its compounds); NA-08
Substance (Second Query); CAS Number	Tetraethyl lead; 78-00-2
Location	Community of Winnipeg (MB)
Facility	All Facilities
Industrial Sectors	All Sectors
Release/Disposal/Transfer Categories	All Types

The most recent reporting threshold for lead (and its compounds) was noted to be 50 kg manufactured, processed or otherwise used (MPO) lead, where "manufactured, processed or otherwise used" refers to the amount of the substance produced, prepared or used in any other way at a facility (ECCC, 2016). In the 2016 and 2017 Guide for Reporting to the NPRI, lead (and its compounds) are identified as a Part 1B substance for its threshold category (ECCC, 2016). Substances in the Part 1B category are referred to as “alternate threshold substances” and have a lower reporting threshold than Part 1A substances. Part 1B substances may have significant environmental or human health impacts in small amounts (ECCC, 2016). In the 2016 and 2017 Guide for Reporting to the NPRI, it was noted that lead (and its compounds) includes the total of pure lead and the equivalent weight of lead contained in any compound, alloy or mixture (ECCC, 2016). It excludes lead (and its compounds) contained in stainless steel, brass or bronze alloys and lead contained in tetraethyl lead (*i.e.,* CAS number presented as “78-00-2”). As indicated in Table A - 1, in addition to conducting an NPRI search of lead and its compounds, tetraethyl lead was also searched in the NPRI database. However, no results were found for tetraethyl lead from the years 1994 to 2017 for facilities in Winnipeg.

The search results for the available reporting years of facilities releasing lead (and its compounds) are presented in Table A - 2. Based on the search for lead and its compounds from 2017, only one facility, Griffin Canada Inc. (*i.e.,* NPRI ID 1344), was reported as having notable lead releases to the air. The release of lead from this facility was 80 kg in 2017 (*i.e.*, 10 kg from stack or point releases and 70 kg from fugitive releases). This facility also was noted to have notable lead releases to the air in preceding years. A second facility, Canadian Pacific

Railway - Weston Powerhouse (*i.e.,* NPRI ID 10826), had on-site air releases of lead, with the highest emission of 52 kg in 2002 and 2004.

Three (3) other facilities (*i.e.,* PPG Phillips Industrial Coatings; Howden Alphair Ventilation System Inc; and SNC Lavalin Profac) were reported to have lead air emissions, however, they were below the reporting threshold. Thirteen (13) additional facilities were identified to have on-site releases (*i.e.,* water, land), disposal on-site, disposal off-site, and/or off-site recycling of lead. Table A - 3 presents the list of the unique locations of the facilities identified from the NPRI search. Table A - 4 presents the applicable facilities with on-site air and land releases.

Given that the NPRI database only dates to 1994, this search may not capture many of the historical point sources of lead emissions in Winnipeg. As such, other potential methods for identifying historical sources of lead were required. The NPRI was contacted to inquire about other resources that may be available that precedes 1994. In a personal communication with the NPRI staff, the 1984 status report on compliance with secondary lead smelter regulations was made available (Environment Canada, 1985).

Table A - 2 NPRI Facility Search Results between 1994 and 2017 Reporting Years													
Reporting Year	**NPRIID**	**Facility**	**City**	**Province**	**On-Site Releases (kg)**				**Disposal (kg) ***			**Off-Site Recycling (kg)**
					Air	**Water**	**Land**	**Total**	**On-Site**	**Off-Site**	**Total**	
2017	**1344**	Griffin Canada Inc. - GRIFFIN CANADA - WINNIPEG	Winnipeg	MB	80	0	0	80	0	2,340	2,340	46,840
	5386	City of Winnipeg, Water & Waste Department - North End Water Pollution Control Centre (NEWPCC)	Winnipeg	MB	0	32	0	32	0	558	558	28
	5387	City of Winnipeg, Water & Waste Department - South End Water Pollution Control Centre (SEWPCC)	Winnipeg	MB	0	8	0	8	0	40	40	0
	2454	Cloverdale Paint Inc. - Guertin Coatings div. of Cloverdale Paint Inc.	Winnipeg	MB	0	0	0	0	0	1.8	1.8	0
	2923	Cadorath Plating Co Ltd. - Head Office	Winnipeg	MB	0	0	0	0	0	0	0	0
	17945	Standard Aero Ltd. - Winnipeg	Winnipeg	MB	0	0	0	0	0	5.6	5.6	0
	24179	Parker Hannifin Canada - Parker Hannifin ECD	Winnipeg	MB	0	0	0	0	0	0	0	962
	Total for All Facilities				**80**	**40**	**0**	**120**	**0**	**2,945**	**2,945**	**47,829**
2016	**1344**	Griffin Canada Inc. - GRIFFIN CANADA - WINNIPEG	Winnipeg	MB	80	0	0	80	0	2,490	2,490	352,400
	5386	City of Winnipeg, Water & Waste Department - North End Water Pollution Control Centre (NEWPCC)	Winnipeg	MB	0	55	0	55	0	572	572	23
	5387	City of Winnipeg, Water & Waste Department - South End Water Pollution Control Centre (SEWPCC)	Winnipeg	MB	0	6.9	0	6.9	0	51	51	0
	2454	Cloverdale Paint Inc. - Guertin Coatings div. of Cloverdale Paint Inc.	Winnipeg	MB	0	0	0	0	0	6.2	6.2	0

Table A - 2 NPRI Facility Search Results between 1994 and 2017 Reporting Years

Reporting Year	NPRIID	Facility	City	Province	On-Site Releases (kg)				Disposal (kg) *			Off-Site Recycling (kg)
					Air	Water	Land	Total	On-Site	Off-Site	Total	
	2923	Cadorath Plating Co Ltd. - Head Office	Winnipeg	MB	0	0	0	0	0	0	0	0
	17945	Standard Aero Ltd. - Winnipeg	Winnipeg	MB	0	0	0	0	0	1.1	1.1	0
	24179	Parker Hannifin Canada - Parker Hannifin ECD	Winnipeg	MB	0	0	0	0	0	0	0	829
	Total for All Facilities				**80**	**62**	**0**	**142**	**0**	**3,120**	**3,120**	**353,252**
2015	**1344**	Amsted Canada Inc. - GRIFFIN CANADA - WINNIPEG	Winnipeg	MB	80	0	0	80	0	2,400	2,400	44,803
	5386	City of Winnipeg, Water & Waste Department - North End Water Pollution Control Centre (NEWPCC)	Winnipeg	MB	0	48	0	48	0	778	778	75
	5387	City of Winnipeg, Water & Waste Department - South End Water Pollution Control Centre (SEWPCC)	Winnipeg	MB	0	12	0	12	0	118	118	0
	2454	Cloverdale Paint Inc. - Guertin Coatings div. of Cloverdale Paint Inc.	Winnipeg	MB	0	0	0	0	0	77	77	0
	2923	Cadorath Plating Co Ltd. - Head Office	Winnipeg	MB	0	0	0	0	0	0	0	0
	17945	Standard Aero Ltd. - Winnipeg	Winnipeg	MB	0	0	0	0	0	0	0	0
	24179	Parker Hannifin Canada - Parker Hannifin ECD	Winnipeg	MB	0	0	0	0	0	0	0	936
	Total for All Facilities				**80**	**60**	**0**	**140**	**0**	**3,374**	**3,374**	**45,814**

Table A - 2 NPRI Facility Search Results between 1994 and 2017 Reporting Years													
Reporting Year	**NPRIID**	**Facility**	**City**	**Province**	**On-Site Releases (kg)**				**Disposal (kg) ***			**Off-Site Recycling (kg)**
					Air	**Water**	**Land**	**Total**	**On-Site**	**Off-Site**	**Total**	
2014	**5386**	City of Winnipeg, Water & Waste Department - North End Water Pollution Control Centre (NEWPCC)	Winnipeg	MB	0	76	0	76	0	951	951	0
	1344	Amsted Canada Inc. - GRIFFIN CANADA - WINNIPEG	Winnipeg	MB	50	0	0	50	0	2,700	2,700	20
	5387	City of Winnipeg, Water & Waste Department - South End Water Pollution Control Centre (SEWPCC)	Winnipeg	MB	0	10	0	10	0	62	62	0
	26120	Howden Alphair Ventilating Systems Inc. - Howden Aliphair - Winnipeg Facility	Winnipeg	MB	0.07	0	0	0.07	0	0	0	37
	2454	Cloverdale Paint Inc. - Guertin Coatings div. of Cloverdale Paint Inc.	Winnipeg	MB	0	0	0	0	0	23	23	0
	2923	Cadorath Plating Co Ltd. - Head Office	Winnipeg	MB	0	0	0	0	0	0	0	0
	17945	Standard Aero Ltd. - Winnipeg	Winnipeg	MB	0	0	0	0	0	2.2	2.2	0
	24179	Parker Hannifin Canada - Parker Hannifin ECD	Winnipeg	MB	0	0	0	0	0	0	0	703
	Total for All Facilities				**50**	**86**	**0**	**136**	**0**	**3,739**	**3,739**	**759**
2013	**1344**	Amsted Canada Inc. - GRIFFIN CANADA - WINNIPEG	Winnipeg	MB	50	0	0	50	0	2,360	2,360	325
	5386	CITY OF WINNIPEG, WATER & WASTE DEPARTMENT - NORTH END WATER POLLUTION CONTROL CENTRE (NEWPCC)	Winnipeg	MB	0	40	0	40	0	1,031	1,031	0
	5387	CITY OF WINNIPEG, WATER & WASTE DEPARTMENT - SOUTH END WATER POLLUTION CONTROL CENTRE (SEWPCC)	Winnipeg	MB	0	11	0	11	0	57	57	0

Table A - 2 NPRI Facility Search Results between 1994 and 2017 Reporting Years													
Reporting Year	**NPRIID**	**Facility**	**City**	**Province**	**On-Site Releases (kg)**				**Disposal (kg) ***			**Off-Site Recycling (kg)**
					Air	**Water**	**Land**	**Total**	**On-Site**	**Off-Site**	**Total**	
	2454	CLOVERDALE PAINT INC. - GUERTIN COATINGS DIV. OF CLOVERDALE PAINT INC.	Winnipeg	MB	0	0	0	0	0	30	30	0
	2923	CADORATH PLATING CO LTD. - SAME	Winnipeg	MB	0	0	0	0	0	0	0	0
	17945	STANDARD AERO LTD. - WINNIPEG	Winnipeg	MB	0	0	0	0	0	1.7	1.7	0
	24179	PARKER HANNIFIN CANADA - PARKER HANNIFIN ECD	Winnipeg	MB	0	0	0	0	0	0	0	1,121
	Total for All Facilities				**50**	**50**	**0**	**100**	**0**	**3,480**	**3,480**	**1,446**
2012	**5386**	CITY OF WINNIPEG, WATER & WASTE DEPARTMENT - NORTH END WATER POLLUTION CONTROL CENTRE (NEWPCC)	Winnipeg	MB	0	42	0	42	0	1,365	1,365	0
	5387	CITY OF WINNIPEG, WATER & WASTE DEPARTMENT - SOUTH END WATER POLLUTION CONTROL CENTRE (SEWPCC)	Winnipeg	MB	0	10	0	10	0	107	107	0
	17365	KEYSTONE AUTOMOTIVE INDUSTRIES ON INC. - NORTHSTAR/FAIRMONT PLATING - WINNIPEG	Winnipeg	MB	0	0.077	0	0.08	0	0	0	0
	24179	PARKER HANNIFIN CANADA - PARKER HANNIFIN ECD	Winnipeg	MB	0	0	0	0	0	0	0	1,014
	1344	AMSTED CANADA INC. - GRIFFIN CANADA - WINNIPEG	Winnipeg	MB	0	0	0	0	0	2,560	2,560	14,170
	2454	CLOVERDALE PAINT INC. - GUERTIN COATINGS DIV. OF CLOVERDALE PAINT INC.	Winnipeg	MB	0	0	0	0	0	119	119	0
	2923	CADORATH PLATING CO LTD. - SAME	Winnipeg	MB	0	0	0	0	0	0	0	0

Table A - 2 NPRI Facility Search Results between 1994 and 2017 Reporting Years

Reporting Year	NPRIID	Facility	City	Province	On-Site Releases (kg)				Disposal (kg) *			Off-Site Recycling (kg)
					Air	Water	Land	Total	On-Site	Off-Site	Total	
	17945	STANDARD AERO LTD. - WINNIPEG	Winnipeg	MB	0	0	0	0	0	0.569	0.57	0
	Total for All Facilities				**0**	**53**	**0**	**53**	**0**	**4,151**	**4,151**	**15,184**
2011	**5386**	CITY OF WINNIPEG, WATER & WASTE DEPARTMENT - NORTH END WATER POLLUTION CONTROL CENTRE (NEWPCC)	Winnipeg	MB	0	56	0	56	0	914	914	0
	5387	CITY OF WINNIPEG, WATER & WASTE DEPARTMENT - SOUTH END WATER POLLUTION CONTROL CENTRE (SEWPCC)	Winnipeg	MB	0	15	0	15	0	78	78	0
	2454	CLOVERDALE PAINT INC. - GUERTIN COATINGS	Winnipeg	MB	0	0	5	5	0	494	494	0
	17365	KEYSTONE AUTOMOTIVE INDUSTRIES ON INC. - NORTHSTAR/FAIRMONT PLATING - WINNIPEG	Winnipeg	MB	0	0.045	0	0.05	0	0	0	0
	762	PPG PHILLIPS INDUSTRIAL COATINGS INC - PPG PHILLIPS INDUSTRIAL COATINGS - WINNIPEG	Winnipeg	MB	0	0	0	0	0	1.1	1.1	0
	1344	AMSTED CANADA INC. - GRIFFIN CANADA - WINNIPEG	Winnipeg	MB	0	0	0	0	0	2,020	2,020	13,100
	24179	PARKER HANNIFIN CANADA - PARKER HANNIFIN ECD	Winnipeg	MB	0	0	0	0	0	0	0	1,061
	2923	CADORATH PLATING CO LTD. - SAME	Winnipeg	MB	0	0	0	0	0	0	0	0
	17945	STANDARD AERO LTD. - WINNIPEG	Winnipeg	MB	0	0	0	0	0	0.519	0.52	0
	Total for All Facilities				**0**	**71**	**5**	**76**	**0**	**3,507**	**3,507**	**14,161**
2010	**5386**	CITY OF WINNIPEG, WATER & WASTE DEPARTMENT - NORTH END WATER POLLUTION CONTROL CENTRE (NEWPCC)	Winnipeg	MB	0	88	0	88	0	817	817	0

Table A - 2	**NPRI Facility Search Results between 1994 and 2017 Reporting Years**											
Reporting Year	**NPRIID**	**Facility**	**City**	**Province**	**On-Site Releases (kg)**				**Disposal (kg) ***			**Off-Site Recycling (kg)**
					Air	**Water**	**Land**	**Total**	**On-Site**	**Off-Site**	**Total**	
	5387	CITY OF WINNIPEG, WATER & WASTE DEPARTMENT - SOUTH END WATER POLLUTION CONTROL CENTRE (SEWPCC)	Winnipeg	MB	0	15	0	15	0	82	82	0
	762	PPG PHILLIPS INDUSTRIAL COATINGS INC - PPG PHILLIPS INDUSTRIAL COATINGS - WINNIPEG	Winnipeg	MB	0	0	0	0	0	1.1	1.1	0
	1344	AMSTED CANADA INC. - GRIFFIN CANADA - WINNIPEG	Winnipeg	MB	0	0	0	0	0	1,380	1,380	5,171
	2454	GUERTIN COATINGS SEALANTS AND POLYMERS - GUERTIN COATINGS	Winnipeg	MB	0	0	0	0	0	147	147	0
	17945	STANDARD AERO LTD. - WINNIPEG	Winnipeg	MB	0	0	0	0	0	0.383	0.38	0
	24179	PARKER HANNIFIN CANADA - PARKER HANNIFIN ECD	Winnipeg	MB	0	0	0	0	0	0	0	2,071
	Total for All Facilities				**0**	**102**	**0**	**102**	**0**	**2,427**	**2,427**	**7,242**
2009	**5386**	CITY OF WINNIPEG - NORTH END WATER POLLUTION CONTROL CENTRE (NEWPCC)	Winnipeg	MB	0	111	0	111	0	851	851	0
	5387	CITY OF WINNIPEG - SOUTH END WATER POLLUTION CONTROL CENTRE (SEWPCC)	Winnipeg	MB	0	14	0	14	0	106	106	0
	5388	CITY OF WINNIPEG - WEST END WATER POLLUTION CONTROL CENTRE (WEWPCC)	Winnipeg	MB	0	7	0	7	0	26	26	0
	2454	GUERTIN COATINGS SEALANTS AND POLYMERS - GUERTIN COATINGS	Winnipeg	MB	0	0	0.5	0.5	0	480	480	0
	17365	NORTHSTAR/FAIRMONT PLATING - NORTHSTAR/FAIRMONT PLATING - WINNIPEG	Winnipeg	MB	0	0.05	0	0.05	0	0	0	0

Table A - 2 NPRI Facility Search Results between 1994 and 2017 Reporting Years													
Reporting Year	**NPRIID**	**Facility**	**City**	**Province**	**On-Site Releases (kg)**				**Disposal (kg) ***			**Off-Site Recycling (kg)**
					Air	**Water**	**Land**	**Total**	**On-Site**	**Off-Site**	**Total**	
	762	PPG PHILLIPS INDUSTRIAL COATINGS - PPG PHILLIPS INDUSTRIAL COATINGS - WINNIPEG	Winnipeg	MB	0	0	0	0	0	0.702	0.7	0
	1344	GRIFFIN CANADA - GRIFFIN CANADA - WINNIPEG	Winnipeg	MB	0	0	0	0	0	665	665	17
	2923	CADORATH PLATING - SAME	Winnipeg	MB	0	0	0	0	0	0	0	0
	17945	STANDARD AERO - WINNIPEG	Winnipeg	MB	0	0	0	0	0	0.323	0.32	0
	Total for All Facilities				**0**	**132**	**0.5**	**132**	**0**	**2,129**	**2,129**	**17**
2008	**5386**	CITY OF WINNIPEG - NORTH END WATER POLLUTION CONTROL CENTRE (NEWPCC)	Winnipeg	MB	0	76	0	76	0	909	909	0
	5387	CITY OF WINNIPEG - SOUTH END WATER POLLUTION CONTROL CENTRE (SEWPCC)	Winnipeg	MB	0	18	0	18	0	78	78	0
	5388	CITY OF WINNIPEG - WEST END WATER POLLUTION CONTROL CENTRE (WEWPCC)	Winnipeg	MB	0	8.4	0	8.4	0	27	27	0
	2454	GUERTIN COATINGS SEALANTS AND POLYMERS - GUERTIN COATINGS	Winnipeg	MB	0	0	0.5	0.5	0	1,094	1,094	0
	22943	SNC LAVALIN PROFAC - RCMP D DIVISION	Winnipeg	MB	0.26	0	0	0.26	0	0	0	0
	17365	NORTHSTAR/FAIRMONT PLATING - NORTHSTAR/FAIRMONT PLATING - WINNIPEG	Winnipeg	MB	0	0.05	0	0.05	0	0	0	0
	762	PPG PHILLIPS INDUSTRIAL COATINGS - PPG PHILLIPS INDUSTRIAL COATINGS - WINNIPEG	Winnipeg	MB	0	0	0	0	0	1.3	1.3	0
	1344	GRIFFIN CANADA - GRIFFIN CANADA - WINNIPEG	Winnipeg	MB	0	0	0	0	0	1,275	1,275	38
	2923	CADORATH PLATING - SAME	Winnipeg	MB	0	0	0	0	0	0	0	0

Table A - 2 NPRI Facility Search Results between 1994 and 2017 Reporting Years												
Reporting Year	NPRIID	Facility	City	Province	On-Site Releases (kg)				Disposal (kg) *			Off-Site Recycling (kg)
					Air	Water	Land	Total	On-Site	Off-Site	Total	
	17945	STANDARD AERO - WINNIPEG	Winnipeg	MB	0	0	0	0	0	0.515	0.52	0
	751	CLOVERDALE PAINT - NORTHERN PAINT	Winnipeg	MB	0	0	0	0	0	31	31	0
	Total for All Facilities				**0.26**	**102**	**0.5**	**103**	**0**	**3,417**	**3,417**	**38**
2007	**5386**	CITY OF WINNIPEG - NORTH END WATER POLLUTION CONTROL CENTRE (NEWPCC)	Winnipeg	MB	0	150	0	150	0	888	888	0
	5388	CITY OF WINNIPEG - WEST END WATER POLLUTION CONTROL CENTRE (WEWPCC)	Winnipeg	MB	0	11	0	11	0	66	66	0
	5387	CITY OF WINNIPEG - SOUTH END WATER POLLUTION CONTROL CENTRE (SEWPCC)	Winnipeg	MB	0	11	0	11	0	117	117	0
	22943	SNC LAVALIN PROFAC - RCMP D DIVISION	Winnipeg	MB	0.26	0	0	0.26	0	0	0	0
	17365	NORTHSTAR/FAIRMONT PLATING - NORTHSTAR/FAIRMONT PLATING - WINNIPEG	Winnipeg	MB	0	0.06	0	0.06	0	0	0	0
	762	PPG PHILLIPS INDUSTRIAL COATINGS - PPG PHILLIPS INDUSTRIAL COATINGS - WINNIPEG	Winnipeg	MB	0.01	0	0	0.01	0	1.3	1.3	0
	1344	GRIFFIN CANADA - GRIFFIN CANADA - WINNIPEG	Winnipeg	MB	0	0	0	0	0	1,174	1,174	38
	2454	GUERTIN COATINGS SEALANTS AND POLYMERS - GUERTIN COATINGS	Winnipeg	MB	0	0	0	0	0	525	525	0
	2923	CADORATH PLATING - SAME	Winnipeg	MB	0	0	0	0	0	0	0	0
	17945	STANDARD AERO - WINNIPEG	Winnipeg	MB	0	0	0	0	0	0.713	0.71	0
	751	CLOVERDALE PAINT - NORTHERN PAINT	Winnipeg	MB	0	0	0	0	0	21	21	0
	6661	CANADIAN FORCES BASE - 17 WING WINNIPEG	Winnipeg	MB	0	0	0	0	0	0	0	17,068

Table A - 2 NPRI Facility Search Results between 1994 and 2017 Reporting Years

Reporting Year	NPRIID	Facility	City	Province	On-Site Releases (kg)				Disposal (kg) *			Off-Site Recycling (kg)
					Air	Water	Land	Total	On-Site	Off-Site	Total	
	6686	MANITOBA HYDRO - RECLAIM	Winnipeg	MB	0	0	0	0	0	0	0	1,967
	Total for All Facilities				**0.27**	**171**	**0**	**172**	**0**	**2,793**	**2,793**	**19,073**
2006	**5386**	CITY OF WINNIPEG - NORTH END WATER POLLUTION CONTROL CENTRE (NEWPCC)	Winnipeg	MB	0	141	0	141	0	1,307	1,307	0
	5387	CITY OF WINNIPEG - SOUTH END WATER POLLUTION CONTROL CENTRE (SEWPCC)	Winnipeg	MB	0	43	0	43	0	108	108	0
	5388	CITY OF WINNIPEG - WEST END WATER POLLUTION CONTROL CENTRE (WEWPCC)	Winnipeg	MB	0	21	0	21	0	62	62	0
	17365	NORTHSTAR/FAIRMONT PLATING - NORTHSTAR/FAIRMONT PLATING - WINNIPEG	Winnipeg	MB	0	0.042	0	0.04	0	0	0	0
	762	PPG PHILLIPS INDUSTRIAL COATINGS - PPG PHILLIPS INDUSTRIAL COATINGS - WINNIPEG	Winnipeg	MB	0	0	0	0	0	1.1	1.1	0
	1344	GRIFFIN CANADA - GRIFFIN CANADA - WINNIPEG	Winnipeg	MB	0	0	0	0	0	1,352	1,352	45
	2454	GUERTIN COATINGS SEALANTS AND POLYMERS - GUERTIN COATINGS	Winnipeg	MB	0	0	0	0	0	575	575	0
	2923	CADORATH PLATING - SAME	Winnipeg	MB	0	0	0	0	0	0	0	0
	751	CLOVERDALE PAINT - NORTHERN PAINT	Winnipeg	MB	0	0	0	0	0	21	21	0
	17945	STANDARD AERO - WINNIPEG	Winnipeg	MB	0	0	0	0	0	0.847	0.85	0
	Total for All Facilities				**0**	**205**	**0**	**205**	**0**	**3,427**	**3,427**	**45**
2005	**5386**	CITY OF WINNIPEG - NORTH END WATER POLLUTION CONTROL CENTRE (NEWPCC)	Winnipeg	MB	0	254	0	254	0	1,821	1,821	0
	5387	CITY OF WINNIPEG - SOUTH END WATER POLLUTION CONTROL CENTRE (SEWPCC)	Winnipeg	MB	0	25	0	25	0	76	76	0

Table A - 2 NPRI Facility Search Results between 1994 and 2017 Reporting Years													
Reporting Year	**NPRIID**	**Facility**	**City**	**Province**	**On-Site Releases (kg)**				**Disposal (kg) ***			**Off-Site Recycling (kg)**
					Air	**Water**	**Land**	**Total**	**On-Site**	**Off-Site**	**Total**	
	5388	CITY OF WINNIPEG - WEST END WATER POLLUTION CONTROL CENTRE (WEWPCC)	Winnipeg	MB	0	14	0	14	0	68	68	0
	762	PPG PHILLIPS INDUSTRIAL COATINGS - PPG PHILLIPS INDUSTRIAL COATINGS - WINNIPEG	Winnipeg	MB	0.01	0	0	0.01	0	1.6	1.6	0
	1344	GRIFFIN CANADA - GRIFFIN CANADA - WINNIPEG	Winnipeg	MB	0	0	0	0	0	1,243	1,243	43
	2454	GUERTIN BROS. COATINGS & SEALANTS - GUERTIN BROS.	Winnipeg	MB	0	0	0	0	0	650	650	0
	2923	CADORATH PLATING - SAME	Winnipeg	MB	0	0	0	0	0	12	12	0
	6686	MANITOBA HYDRO - RECLAIM	Winnipeg	MB	0	0	0	0	0	0	0	19,000
	17945	STANDARD AERO - WINNIPEG	Winnipeg	MB	0	0	0	0	0	0.056	0.06	0
	17365	NORTHSTAR/FAIRMONT PLATING - NORTHSTAR/FAIRMONT PLATING - WINNIPEG	Winnipeg	MB	0	0	0	0	0	0	0	0
	751	CLOVERDALE PAINT - NORTHERN PAINT	Winnipeg	MB	0	0	0	0	0	46	46	0
	Total for All Facilities				**0.01**	**293**	**0**	**293**	**0**	**3,917**	**3,917**	**19,043**
2004	**5386**	CITY OF WINNIPEG - NORTH END WATER POLLUTION CONTROL CENTRE (NEWPCC)	Winnipeg	MB	0	224	0	224	0	1,450	1,450	0
	5387	CITY OF WINNIPEG - SOUTH END WATER POLLUTION CONTROL CENTRE (SEWPCC)	Winnipeg	MB	0	78	0	78	0	0	0	0
	10826	CANADIAN PACIFIC RAILWAY - WESTON POWERHOUSE	Winnipeg	MB	52	0	0	52	0	13	13	0
	5388	CITY OF WINNIPEG - WEST END WATER POLLUTION CONTROL CENTRE (WEWPCC)	Winnipeg	MB	0	40	0	40	0	66	66	0

Table A - 2 NPRI Facility Search Results between 1994 and 2017 Reporting Years													
Reporting Year	NPRIID	Facility	City	Province	On-Site Releases (kg)				Disposal (kg) *			Off-Site Recycling (kg)
					Air	Water	Land	Total	On-Site	Off-Site	Total	
	2454	GUERTIN COATINGS SEALANTS AND POLYMERS - GUERTIN COATINGS	Winnipeg	MB	0	0	6	6	0	800	800	0
	762	PPG PHILLIPS INDUSTRIAL COATINGS - PPG PHILLIPS INDUSTRIAL COATINGS - WINNIPEG	Winnipeg	MB	0.01	0	0	0.01	0	1.7	1.7	0
	1344	GRIFFIN CANADA - GRIFFIN CANADA - WINNIPEG	Winnipeg	MB	0	0	0	0	0	1,141	1,141	41
	2923	CADORATH PLATING - SAME	Winnipeg	MB	0	0	0	0	0	82	82	2,657
	629	BOEING CANADA OPERATIONS LTD. - BOEING CANADA OPERATIONS LTD.	Winnipeg	MB	0	0	0	0	0	0	0	0
	17945	STANDARD AERO - WINNIPEG	Winnipeg	MB	0	0	0	0	0	0.099	0.1	0
	17365	NORTHSTAR/FAIRMONT PLATING - NORTHSTAR/FAIRMONT PLATING - WINNIPEG	Winnipeg	MB	0	0	0	0	0	0	0	0
	6686	MANITOBA HYDRO - RECLAIM	Winnipeg	MB	0	0	0	0	0	0	0	14,500
	Total for All Facilities				**52**	**342**	**6**	**400**	**0**	**3,553**	**3,553**	**17,198**
2003	**5386**	CITY OF WINNIPEG, WATER & WASTE DEPARTMENT - NORTH END WATER POLLUTION CONTROL CENTRE (NEWPCC)	Winnipeg	MB	0	598	0	598	0	1,486	1,486	0
	5387	CITY OF WINNIPEG, WATER & WASTE DEPARTMENT - SOUTH END WATER POLLUTION CONTROL CENTRE (SEWPCC)	Winnipeg	MB	0	198	0	198	0	0	0	0
	5388	CITY OF WINNIPEG, WATER & WASTE DEPARTMENT - WEST END WATER POLLUTION CONTROL CENTRE (WEWPCC)	Winnipeg	MB	0	79	0	79	20	50	70	0

Table A - 2 NPRI Facility Search Results between 1994 and 2017 Reporting Years													
Reporting Year	**NPRIID**	**Facility**	**City**	**Province**	**On-Site Releases (kg)**				**Disposal (kg) ***			**Off-Site Recycling (kg)**
					Air	**Water**	**Land**	**Total**	**On-Site**	**Off-Site**	**Total**	
	10826	CANADIAN PACIFIC RAILWAY - WESTON POWERHOUSE	Winnipeg	MB	51	0	0	51	0	87	87	0
	2454	GUERTIN BROS. COATINGS & SEALANTS LTD. - GUERTIN BROS.	Winnipeg	MB	0	0	7	7	0	1,200	1,200	0
	762	PPG PHILLIPS INDUSTRIAL COATINGS	Winnipeg	MB	0.01	0	0	0.01	0	2.1	2.1	0
	1344	GRIFFIN CANADA - GRIFFIN CANADA - WINNIPEG	Winnipeg	MB	0	0	0	0	0	911	911	36
	629	BOEING CANADA TECHNOLOGY LTD. - WINNIPEG DIVISION	Winnipeg	MB	0	0	0	0	0	0	0	0
	6686	MANITOBA HYDRO - RECLAIM	Winnipeg	MB	0	0	0	0	0	0	0	3,000
	2923	CADORATH PLATING CO. LTD.	Winnipeg	MB	0	0	0	0	0	93	93	3,001
	17365	NORTHSTAR/FAIRMONT PLATING LTD	Winnipeg	MB	0	0	0	0	0	0	0	0
	Total for All Facilities				**51**	**875**	**7**	**933**	**20**	**3,828**	**3,848**	**6,037**
2002	**5386**	CITY OF WINNIPEG, WATER & WASTE DEPARTMENT - NORTH END WATER POLLUTION CONTROL CENTRE (NEWPCC)	Winnipeg	MB	0	427	0	427	0	1,986	1,986	0
	6897	CITY OF WINNIPEG, WATER & WASTE DEPARTMENT - WASTEWATER COLLECTION SYSTEM	Winnipeg	MB	0	292	0	292	0	0	0	0
	5387	CITY OF WINNIPEG, WATER & WASTE DEPARTMENT - SOUTH END WATER POLLUTION CONTROL CENTRE (SEWPCC)	Winnipeg	MB	0	123	0	123	0	287	287	0
	5388	CITY OF WINNIPEG, WATER & WASTE DEPARTMENT - WEST END WATER POLLUTION CONTROL CENTRE (WEWPCC)	Winnipeg	MB	0	65	0	65	0	76	76	0

Table A - 2 NPRI Facility Search Results between 1994 and 2017 Reporting Years												
Reporting Year	**NPRIID**	**Facility**	**City**	**Province**	**On-Site Releases (kg)**				**Disposal (kg) ***			**Off-Site Recycling (kg)**
					Air	**Water**	**Land**	**Total**	**On-Site**	**Off-Site**	**Total**	
	10826	CANADIAN PACIFIC RAILWAY - WESTON POWERHOUSE	Winnipeg	MB	52	0	0	52	0	87	87	0
	2454	GUERTIN BROS. COATINGS & SEALANTS LTD. - GUERTIN BROS.	Winnipeg	MB	0	0	10	10	0	1,500	1,500	0
	762	PPG PHILLIPS INDUSTRIAL COATINGS	Winnipeg	MB	0.01	0	0	0.01	0	0.017	0.02	0
	5268	CANADA METAL (WESTERN) LIMITED	Winnipeg	MB	0	0	0	0	0	0	0	0
	6686	MANITOBA HYDRO - RECLAIM	Winnipeg	MB	0	0	0	0	0	0	0	1,000
	Total for All Facilities				**52**	**907**	**10**	**969**	**0**	**3,936**	**3,936**	**1,000**
2001	**5386**	City of Winnipeg - North End Water Pollution Control Centre (NEWPCC)	Winnipeg	MB	0	0.407	0	0.41	0	2.9	2.9	0
	5387	City of Winnipeg - South End Water Pollution Control Centre (SEWPCC)	Winnipeg	MB	0	0.116	0	0.12	0	0.488	0.49	0
	2454	Guertin Bros. Coatings & Sealants Ltd. - Guertin Bros.	Winnipeg	MB	0	0	0	0.1	0	1.8	1.8	0
	5388	City of Winnipeg - West End Water Pollution Control Centre (WEWPCC)	Winnipeg	MB	0	0.06	0	0.06	0	0.097	0.1	0
	5268	Canada Metal - Canada Metal Western	Winnipeg	MB	0	0	0	0.05	0	0	0	0
	Total for All Facilities				**0**	**0.583**	**0**	**0.73**	**0**	**5.2**	**5.2**	**0**
2000	**2454**	Guertin Bros. Coatings & Sealants Ltd. - Guertin Bros.	Winnipeg	MB	0	0	0	0.1	0	2	2	0
	5268	Canada Metal - Canada Metal Western	Winnipeg	MB	0	0	0	0.05	0	0	0	0
	Total for All Facilities				**0**	**0**	**0**	**0.15**	**0**	**2**	**2**	**0**
1999	**2454**	Guertin Bros. Coatings & Sealants Ltd. - Guertin Bros.	Winnipeg	MB	0	0	0	0.1	0	2	2	0
	5268	Canada Metal (Western) Ltd. - Winnipeg	Winnipeg	MB	0	0	0	0.05	0	0	0	0

Table A - 2 NPRI Facility Search Results between 1994 and 2017 Reporting Years

Reporting Year	NPRIID	Facility	City	Province	On-Site Releases (kg)				Disposal (kg) *			Off-Site Recycling (kg)
					Air	Water	Land	Total	On-Site	Off-Site	Total	
	Total for All Facilities				**0**	**0**	**0**	**0.15**	**0**	**2**	**2**	**0**
1998	**2454**	Guertin Bros. Coatings & Sealants Ltd. - Guertin Bros.	Winnipeg	MB	0	0	0	0.1	0	3.9	3.9	0
	5268	Canada Metal (Western) Ltd. - Winnipeg	Winnipeg	MB	0	0	0	0.1	0	0	0	500
	Total for All Facilities				**0**	**0**	**0**	**0.2**	**0**	**3.9**	**3.9**	**500**
1997	**2454**	Guertin Bros. Coatings & Sealants Ltd. - Guertin Bros.	Winnipeg	MB	0	0	0	0.1	0	4.2	4.2	0
	Total for All Facilities				**0**	**0**	**0**	**0.1**	**0**	**4.2**	**4.2**	**0**
1996	**2454**	Guertin Bros. Coatings & Sealants Ltd. - Guertin Bros.	Winnipeg	MB	0	0	0	0.1	0	3.7	3.7	0
	Total for All Facilities				**0**	**0**	**0**	**0.1**	**0**	**3.7**	**3.7**	**0**
1995	**2454**	Guertin Bros. Coatings & Sealants Ltd.	Winnipeg	MB	0	0	0	0.1	0	3.4	3.4	0
	Total for All Facilities				**0**	**0**	**0**	**0.1**	**0**	**3.4**	**3.4**	**0**
1994	**2454**	Guertin Brothers Coatings & Sealants	Winnipeg	MB	0	0	0	0.13	0	3	3	0
	Total for All Facilities				**0**	**0**	**0**	**0.13**	**0**	**3**	**3**	**0**

* As of the 2006 reporting year, the Disposal columns include information on tailings and waste rock disposals. Negative numbers are possible for on-site disposal of tailings and waste rock, which would reflect a net removal of the substances from the tailings or waste rock management area. Please note that negative values are not counted in the total for all facilities.

Table A - 3 List of the Unique Locations of The Facilities Identified from the NPRI Search

NPRIID	Facility	Address	City	Province
1344	Griffin Canada Inc. - GRIFFIN CANADA - WINNIPEG	2500 Day Street	Winnipeg	MB
2454	Cloverdale Paint Inc. - Guertin Coatings div. of Cloverdale Paint Inc.	50 Panet Road	Winnipeg	MB
2923	Cadorath Plating Co Ltd. - Head Office	2150 Logan Avenue	Winnipeg	MB
5386	City of Winnipeg, Water & Waste Department - North End Water Pollution Control Centre (NEWPCC)	2230 Main Street	Winnipeg	MB
5387	City of Winnipeg, Water & Waste Department - South End Water Pollution Control Centre (SEWPCC)	100 Ed Spencer Drive	Winnipeg	MB
17945	Standard Aero Ltd. - Winnipeg	33 Allen Dyne Road	Winnipeg	MB
24179	Parker Hannifin Canada - Parker Hannifin ECD	1305 Clarence Avenue	Winnipeg	MB
26120	Howden Alphair Ventilating Systems Inc. - Howden Aliphair - Winnipeg Facility	1221 Sherwin Road	Winnipeg	MB
17365	KEYSTONE AUTOMOTIVE INDUSTRIES ON INC. - NORTHSTAR/FAIRMONT PLATING - WINNIPEG	4 Chester Street	Winnipeg	MB
762	PPG PHILLIPS INDUSTRIAL COATINGS INC - PPG PHILLIPS INDUSTRIAL COATINGS - WINNIPEG	95 Paquin Road	Winnipeg	MB
5388	CITY OF WINNIPEG - WEST END WATER POLLUTION CONTROL CENTRE (WEWPCC)	7740 Wilkes Avenue	Winnipeg	MB
751	CLOVERDALE PAINT - NORTHERN PAINT	394 Gertrude Avenue	Winnipeg	MB
22943	SNC LAVALIN PROFAC - RCMP D DIVISION	1091 Portage Avenue	Winnipeg	MB
6661	CANADIAN FORCES BASE - 17 WING WINNIPEG	17 Wing Winnipeg	Winnipeg	MB
6686	MANITOBA HYDRO - RECLAIM	1840 Chevrier Blvd	Winnipeg	MB
10826	CANADIAN PACIFIC RAILWAY - WESTON POWERHOUSE	478 McPhillips Street	Winnipeg	MB
5268	CANADA METAL (WESTERN) LIMITED	1221 St. James St.	Winnipeg	MB
6897	CITY OF WINNIPEG, WATER & WASTE DEPARTMENT - WASTEWATER COLLECTION SYSTEM	360 McPhillips Street	Winnipeg	MB

* As of the 2006 reporting year, the Disposal columns include information on tailings and waste rock disposals. Negative numbers are possible for on-site disposal of tailings and waste rock, which would reflect a net removal of the substances from the tailings or waste rock management area. Please note that negative values are not counted in the total for all facilities.

Table A - 4 Locations of the Applicable NPRI Facilities with On-site Air and Land Releases

NPRIID	Facility	Address	City	Province
1344	Griffin Canada Inc. - GRIFFIN CANADA - WINNIPEG	2500 Day Street	Winnipeg	MB
2454	Cloverdale Paint Inc. - Guertin Coatings div. of Cloverdale Paint Inc.	50 Panet Road	Winnipeg	MB
26120	Howden Alphair Ventilating Systems Inc. - Howden Aliphair - Winnipeg Facility	1221 Sherwin Road	Winnipeg	MB
762	PPG PHILLIPS INDUSTRIAL COATINGS INC - PPG PHILLIPS INDUSTRIAL COATINGS - WINNIPEG	95 Paquin Road	Winnipeg	MB
22943	SNC LAVALIN PROFAC - RCMP D DIVISION	1091 Portage Avenue	Winnipeg	MB
10826	CANADIAN PACIFIC RAILWAY - WESTON POWERHOUSE	478 McPhillips Street	Winnipeg	MB
5268	CANADA METAL (WESTERN) LIMITED	1221 St. James St.	Winnipeg	MB

* As of the 2006 reporting year, the Disposal columns include information on tailings and waste rock disposals. Negative numbers are possible for on-site disposal of tailings and waste rock, which would reflect a net removal of the substances from the tailings or waste rock management area. Please note that negative values are not counted in the total for all facilities.

A-1.2 Henderson Winnipeg Directories

Intrinsik searched the Henderson library directory, available through the Peel's Prairie Provinces Collection of the University of Alberta Libraries, to identify historical sources of lead in Winnipeg. The Henderson library directory was described as including names of the citizens, streets of the city, and businesses of Manitoba between the years 1920 to 1956.

The use of the directories was not helpful in determining historical sources of lead contamination as the directories do not provide detailed information on the nature of the business or the potential for lead emissions.

A-1.3 Environment Assessment and Licencing Public Registry Search

As the NPRI search was limited to information dating back to 1994, additional methods for identifying potential current and historical sources of lead was required. Through an inquiry from the Oversight Committee, the department of Sustainable Development recommended that the Public Registry under the Manitoba Environment Act (EA) Licencing Process be reviewed. The Public Registry includes proposals and EA licences of projects and developments which fall under the *Environmental Assessment Act*, the *Dangerous Goods Handling and Transportation Act*, and any other activities which require posting in public registry system. The EA licensing began in 1988, and licensing under the *Clean Environment Act* began in the 1970s.

Registry searches were conducted using two approaches. The first approach included a search of the known smelter facilities (*e.g.,* Canadian Bronze Company Ltd., Canada Metal Co., Northwest Smelting Co.). The second approach was to use keywords to search the registry. Both approaches are discussed further in detail below.

Through conducting searches through both approaches, several facilities were identified as having/had a licence that addressed environmental releases of lead. As such, additional information was requested from the Sustainable Development department to determine if there were reports which may provide air emissions data. Table A - 5 presents the results of the search for additional information for these licences. Many licences do not have additional studies on file. As such, the identified facilities may be potential sources of lead in Winnipeg, but without further information, the extent of potential contamination is unknown.

Table A - 5 Requested Licences for Review

Client File Number	Licence Number	Licence Issued To	Date of Issue	Location of Development	Description of Development	Clauses Addressing Lead Emissions	Monitoring/ Studies	Studies on File	Status of File	RP/ Remediation
507.2 [a]	1128	The Canadian Bronze Company Ltd	10-Nov-87	15 Bury Avenue	Non-ferrous foundry	C. 2 - lead	C. 5 - conduct emission testing once every 3 years. Report due w/in 90 days of testing.	Unknown - file not available for review	Archived	Several Remedial Plans on file as well as reports
5972.00 & 5699.00 [d]	Not issued	Rakowski Recycling	-	454 Archibald Street	Scrap Metal Processing (ferrous & non-ferrous)	-	-	none on file	Licence in Process	N/A
508.1 [a]	768 R	Dixon Group Canada	27-Jan-78	2200 Logan Avenue	Foundry (aluminum, Bronze, Copper, & Zinc)	C.7 - particulate matter emission limits.	C.16 - 22 - conduct emissions testing at the request of the Director.	no studies on file. There are 3 EO Reports from the 70's on file that may be of some interest.	Operating	N/A
2846 [c]	1163	Nuwest Alloys	18-Feb-88	2141 Logan Avenue	Non-ferrous foundry	C.5 - lead	C.10 - conduct emissions testing at the request of the Environmental Management Division.	No studies on file.	Licence Cancelled	N/A
2625 [d]	1019	Shell Canada Ltd.	29-May-84	250 Panet Road	Oil Refinery	-	C.7 - soil & GW monitoring.	File not in cabinet - review incomplete	Operating	Several Remedial Plans on file as well as reports
5669 [c]	272 HW	Direct General Partner Corp.	17-Jan-14	55 Rothwell Road	Waste Lead Acid Battery Transfer Station	-	C.32 & 33 - Conduct ESA at closure of the facility.	Phase 1 ESA attached in Appendix A of the DG Proposal.	Licence Cancelled	N/A

Table A - 5 Requested Licences for Review

Client File Number	Licence Number	Licence Issued To	Date of Issue	Location of Development	Description of Development	Clauses Addressing Lead Emissions	Monitoring/ Studies	Studies on File	Status of File	RP/ Remediation
5778 [d]	286 HW	Western Scrap Metals Inc.	03-Sep-15	18 Sutherland Avenue	Waste Lead Acid Battery Transfer Station	-	C.38 & 39 - Conduct ESA at closure of the facility.	No studies on file.	Operating	N/A
5364 [d]	265 HW	Chisick Metals (2000) Ltd and 4316681 Canada Inc. o/a Industrial Metals (2011)	03-Jul-12	550 Messier Street	Waste Lead Acid Battery Transfer Station	-	C.21 & 22 - Conduct ESA at closure of the facility.	Unknown - file not available for review	Operating	N/A
4276 [d]	238 HW R	Evraz Recycling Inc; General Scrap Partnership o/a General Scrap	15-Dec-08	135 Bismarck Street	Waste Lead Acid Battery Transfer Station	-	C.22 & 23 - Conduct ESA at closure of the facility.	No studies on file.	Operating	N/A
4295 [d]	232 HW R	Sametco Auto Inc a Division of Evraz Inc o/a Logan Iron and Metal Company Ltd	21-Apr-08	1021 Logan Avenue	Waste Lead Acid Battery Transfer Station	-	C.21 & 22 - Conduct ESA at closure of the facility.	No studies on file.	Operating	Remedial Plan and Closure Report on File
5095 [d]	194 HW RR	Urbanmine Inc	18-Aug-05	410 Madison Street	Waste Lead Acid Battery Transfer Station	-	C.21 & 22 - Conduct ESA at closure of the facility.	Unknown - file not available for review	Operating	Several Reports on File
4606 [b]	129 HW	Deviet Enterprises Ltd	21-Jun-01	216-79 Eagle Drive	Waste Lead Acid Battery Transfer Station	-	C.18 & 19 - Conduct ESA at closure of the facility.	Unknown - file not available for review	Operating	N/A
4566 [d]	123 HW	Exide Canada Inc.	21-Feb-01	4 Stevenson Road	Waste Lead Acid Battery	-	C.18 & 19 - Conduct ESA	Unknown - file not	Licence Rescinded	N/A

Table A - 5 Requested Licences for Review										
Client File Number	**Licence Number**	**Licence Issued To**	**Date of Issue**	**Location of Development**	**Description of Development**	**Clauses Addressing Lead Emissions**	**Monitoring/ Studies**	**Studies on File**	**Status of File**	**RP/ Remediation**
					Transfer Station		at closure of the facility.	available for review		
4750 [c]	141 HW	4213793 Manitoba Ltd o/a Prairie Battery	07-May-02	105 Paramount Road	Waste Lead Acid Battery Transfer Station	-	C.19 & 20 - Conduct ESA at closure of the facility.	Unknown - file not available for review	Operating	N/A
4969 [b]	173 HW	Battery Direct of Manitoba Inc	17-Oct-03	3-2073 Logan Avenue	Waste Lead Acid Battery Transfer Station	-	C.19 & 20 - Conduct ESA at closure of the facility.	Unknown - file not available for review	Licence Cancelled	N/A
2406 [a]	1072	Varta Batteries Ltd	24-Jun-85	1717 Wellington Avenue	Lead Acid Battery Manufacturing Plant	C. 1, 2, 7	-	Unknown - file not available for review	Decommissioned	Several Reports on File
993 [b]	452	Controller Environments Ltd	14-May-75	661 Century Street & 1461 St James Street	Manufacturing of Scientific Research Equipment	C. 2 - Particulate	-	No studies on file.	Licence Cancelled	N/A
5873[d]	3227	West End Radiators	31-Aug-17	1940, 2008, 2010, & 2020 Logan Avenue	Radiator manufacturing facility	C. 9 - lead	C. 18 - 24 - Air Emissions Monitoring.	Refer to June 16, 2017 email re - EAP comments on air emissions	Operating	N/A
4509 [b]	2528 E RR	New Flyer Industries Ltd	08-Nov-01	SW 05-11-04 EPM	Bus manufacturing facility	C. 10 - Particulate	C. 22 - 27, 32, 33 - Air Emissions Monitoring.	Unknown - file not available for review	Operating	Two Reports on File
3512 [b]	1628	Perry's Machine Shop Ltd	04-Feb-93		Manufacturing & Industrial Plant	C. 10, 11 - Lead	C. 13, 14	Unknown - file not available for review		N/A

a Permanently Archived, we cannot retrive
b Semi- Archived, we will have to request these files
c Closed Retain, Region file is closed
d Active, Region has the file

A-1.3.1 Search of Specific Smelters

The registry was searched for the secondary lead smelters that were known to exist in the Weston area (*e.g*., Canadian Bronze Company Ltd., Canada Metal Co., Northwest Smelting Co.,). This was done with the intention of identifying emission data for these facilities, as well as to act as a check to ensure that the search of the database was able to identify facilities with known lead emissions. This search only identified a document for the Canadian Bronze Company Limited (File number 507.20 and Licence number 1128), where it indicated the following:

> *Subject to Clause 4, the Applicant shall not cause or permit the emission of lead from the operations referred to in Clause 1 in excess of 0.0145 grams per standard cubic metre, when measured by the methods described in Environment Canada Report EPS-1-AP-78-3, 'Standard Reference Methods for Source Testing: Measurement of Emissions of Particulate Matter and Lead from Secondary Lead Smelters', dated June 1979 or as measured by any other method approved in advance in writing by the Environmental Management Division.*

A request was made to the Oversight Committee to check archived documents to determine if any additional files were available, however, the studies on file are unknown and files are not available for review.

It was determined that the Canadian Bronze smelter was identified as “Non-Ferrous foundry” for project name, and as such, an additional search was conducted using “Non-Ferrous foundry” as a keyword for the second approach discussed in Section A-1.3.2.

A-1.3.2 Individual Keyword Searches (i.e., refinery; non-ferrous foundry; smelter; lead; manufacturing; manufacturing and industrial plant)

Under the Manitoba Classes of Development Regulation 164/88, smelters are listed under “refinery”, which is defined as “a plant where products from a smelter or milling facility are processed to further remove impurities from the final mineral product”. As such, searches for individual keywords in the registry were conducted (*i.e.*, refinery; non-ferrous foundry; smelter; lead; manufacturing; manufacturing and industrial plant).

To determine if the results of a query were applicable, the location of the project (*i.e.,* project located in Winnipeg) and an indication of potential lead emissions or emissions of metals were considered. The files which passed this screening process were retained, with details of the project such as the file number, licence issue date, address of the project, and any other relevant information recorded. These files were then presented to the Oversight committee to determine if additional information exists which may be archived and not digitally available on the Public Registry.

The registry has organized projects under three categories: open for comment, in process, and completed. A search using the individual keywords was conducted in all three categories. The results are provided in Table A - 6 below. Details associated with file numbers are presented in Table A - 5.

Table A - 6 File Numbers of Applicable Search Results Identified by Individual Categories			
Keywords	**File number**		
	Open	**In Process**	**Completed**
“refinery”	-	-	2625
“non-ferrous foundry”	-	-	508.1 507.20 2846.00
“smelter”	-	-	-
“lead”	-	5972	5669 5778 5364 4276 4276 4295 5095 4606 4566 4750 4969 2406
“manufacturing”	-	-	993 5873 3512 2406
“manufacturing and industrial plant"	-	-	4509 3512

A-2. REFERENCES

Environment and Climate Change Canada (ECCC). 2016. Guide for Reporting to the National Pollutant Release Inventory -2016 and 2017. Cat. No. En81-1E-PDF. ISSN1480-6622. Available at: http://publications.gc.ca/collections/collection_2016/eccc/En81-1-2017-eng.pdf

Environment and Climate Change Canada (ECCC). 2018. National Pollutant Release Inventory (NPRI) Online Facility Data Search. Available at: https://pollution-waste.canada.ca/national-release-inventory/archives/index.cfm?lang=en

APPENDIX B

Supplemental Information for Jurisdictional Review

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B-1.0 INTRODUCTION

This Appendix is intended to supplement the information provided within Section 4 of the main report.

B-1.1 Blood Lead and Health

Several recent (within the last 10 years) reviews of the health effects of blood lead were identified from regulatory agencies and organisations with respect to non-occupational exposures. These reports are summarized briefly within Table B- 1 with respect to key findings.

Table B- 1 Summary of Recent Comprehensive Review Documents Completed by Regulatory Agencies Regarding Lead Exposure and Human Effects

Agency/Organization	Publication Date	Title	Findings
Australia National Health and Medical Research Council (NHMRC)	2014,2015	Evaluation of Evidence Related to Exposure to Lead NHMRC Information Paper: Evidence on the Effects of Lead on Human Health	• Adverse health effects in children, particularly cognitive effects (e.g. IQ decrements) are associated with BLLs less than or equal to 10 µg/dL. However, the potential for confounding in the key studies of children with these BLLs was identified by the reviewers. • BLL less than the intervention level of 10 µg/dL were associated with adverse behavioural effects in children, delays in sexual maturation or puberty onset in adolescent girls and boys, and increased blood pressure and risk of hypertension in adults and pregnant women. • There is limited evidence regarding the effectiveness of interventions in reducing BLLs due to risk of bias and imprecision. Interventions studies included chelation therapy, pharmacological interventions (calcium or iron supplementation), physical/environmental (home remediation, cleaning). Most of the intervention studies evaluated included children with BLL > 10 µg/dL.
US Agency for Toxic Substances and Disease Registry (ATSDR)	2019	Toxicological Profile for Lead. Draft for Public Comment.	• Focus of review of health effects was intentionally on BLLs less than 5 µg/dL in children. • Several studies observed significant neurological and behavioural effects in children in association with BLLs less than 5 µg/dL, following prenatal or environmental exposures to low levels of lead. • No clear evidence of a threshold or safe level of exposure is evident, and a minimal risk level (MRL) was not derived for lead. • Additional studies are not likely to result in the identification of threshold-based values for health effects associated with lead. • Adverse neurological, renal, and cardiovascular effects in adults have been observed at BLLs ranging from less than 5 µg/dL to more than 50 µg/dL. Childhood exposures may influence adult outcomes. Adverse immunological, hematological and reproductive effects have been observed in several studies of adults with BLLs of 10 µg/dL and above. • The database of human studies regarding lead carcinogenicity are inconsistent, but several studies do show evidence of increased cancer risks both above and below 10 µg/dl.
US Center for Disease Control, Advisory Committee on Childhood Lead Poisoning Prevention (ACLPP)	2012	Low Level Lead Exposure Harms Children: A Renewed Call for Primary Prevention.	• Available weight of evidence suggests that BLLs of less than 10 µg/dL are associated with adverse effects on neurocognitive development in children, behavioural effects, cardiovascular, immunological and endocrine effects. These effects appear to be irreversible. • The effects of lead in older children are not as well studied as in young children. • The term 'blood lead level of concern' should no longer be used, as no level of exposure is without concern. • The adverse health effects of lead are not conclusively linked to any particular socioeconomic status, although racial and income disparities do exist. • Primary prevention strategies are recommended to emphasize the reduction and prevention of lead exposure, rather than strategies being implemented after exposures have occurred. • Any child with a BLL above 5 µg/dL (defined in this report as a reference level) is likely exposed to lead via one or more pathways. Exposures to lead in homes or child-occupied facilities significantly contribute to BLLs above this level. • Evidence that nutritional interventions are effective for modifying BLLs is limited. • It is recommended that education and environmental assessments for children at risk of lead exposure be conducted before screening for BLLs.

Table B- 1 Summary of Recent Comprehensive Review Documents Completed by Regulatory Agencies Regarding Lead Exposure and Human Effects

Agency/Organization	Publication Date	Title	Findings
European Food Safety Agency (EFSA)	2012	Scientific opinion on lead in food	• Dust and soil are important non-dietary exposure pathways for lead, while cereals and vegetables contribute the most to dietary exposure. Drinking water is also a source of lead exposure. • Developmental neurotoxicity in young children and cardiovascular effects and renal (kidney) effects in adults were identified as the critical effects for the risk assessment completed as part of this report. Blood lead levels in children are inversely related to IQ and cognitive deficits up to age 7-years. • No clear threshold for critical lead-induced effects were apparent from the review. • The Provisional Tolerable Weekly Intake Level recommended by the WHO at the time (25 µg/kg-day) was no longer appropriate, given the lack of a clear threshold. • The protection of children against the adverse neurodevelopmental effects of lead would be protective for all other potential effects of lead, in all age groups. • Benchmark-dose models were used (using a non-threshold approach and a level of 1% extra risk) to identify for neurodevelopmental effects in children (0.50 µg/kg-day), chronic kidney disease in adults (0.64 µg/kg-day), and increased systolic blood pressure (1.5 µg/kg-day). • The estimated lead exposure to children ages 0 to 7 years in Europe was found to exceed the $BMDL_{01}$ intake of 0.50 µg/kg-day. It was also concluded that women of reproductive age (20-40 years) had lead intakes associated with some risk of adverse effects to a developing fetus. • The current levels of adult exposure in Europe were below the benchmark levels for cardiovascular or kidney effects.
Health Canada	2013	Final Human Health State of the Science Report on Lead.	• BLLs in Canada have declined by over 70% since 1978-1979, but lead is still detectable in Canadians. • Oral exposures from food and water are the primary pathways of exposure, with ingestion of non-food items containing lead (dust, soil, lead-paint, consumer products) being important additional exposure pathways for infants and children. • Significant evidence of adverse health effects has been observed at BLLs below 10 µg/dL and as low as 1 to 2 µg/dL for developmental neurotoxicity in children. Developmental neurotoxic effects include: neuromotor function, academic achievement and reading or math skills, delinquent or antisocial behaviour, attention and executive functioning deficits, auditory and visual function impairment. • The adverse effects of lead from childhood exposures can persist into late adolescence. • Animal studies indicate that the developmental neurotoxic effects of lead can persist for long periods after exposure has been discontinued and blood and brain lead concentrations have returned to control levels. • Lead can interact with different cell types within the nervous system. • Infants and children should be considered as sensitive subpopulations for neurodevelopmental effects, as this health effect is considered to be protective for other adverse health effects in the population as a whole. • Dose-response modelling does not support the identification of a threshold for developmental neurotoxic effects. For some effect endpoints, namely IQ deficits, the dose-response relationship seems to be curvilinear, with a steeper slope of the lower levels of environmental lead exposures.

Table B- 1 Summary of Recent Comprehensive Review Documents Completed by Regulatory Agencies Regarding Lead Exposure and Human Effects

Agency/Organization	Publication Date	Title	Findings
			• For many of the low-level studies evaluated, the limit of quantification of lead in blood was approximately 3 µg/dL. As a result, BLL measurements below this level are associated with some uncertainty.
Health Canada	2019	Guidelines for Canadian Drinking Water Quality – Guideline Technical Document - Lead	• There is consistent evidence in humans of delayed puberty in females exposed to lead at BLLs as low as 1.2 µg/dL and suggestive evidence of lead being associated with earlier menopause. • A significant number of studies have associated low BLLs (<10 µg/dL) with neurodevelopmental effects in children. In addition, there is evidence that suggests that lead exposure is associated with attention-related deficits, including attention deficit hyperactivity disorder (ADHD) at BLLs less than 5 µg/dL. It is hypothesized that effects on attention may be an underlying cause of deceases in IQ. BLLs as low as 0.8 µg/dL have been associated with neurodevelopmental effects in children (IQ). • Four meta-analyses of the data regarding prenatal and postnatal BLLs in children and an association with IQ decrements (as revealed by psychometric testing) concluded that the weight of epidemiological evidence supports an association, with maternal and cord BLLs below 5 µg/dL associated with adverse effects on intelligence, memory and cognition. • Decreases in IQ are not likely to occur equally within the population, due to existing differences in the population with respect to intellectual functioning. • There is an apparent association between in utero exposures to lead with adverse neurodevelopmental outcomes. • The lowest BLL associated with adverse neurodevelopmental effects cannot be identified; a non-threshold approach using low-dose linear extrapolations should be used to evaluate points of departure for risk estimates. • Generally, neurodevelopmental effects associated with lead occur at much lower concentrations than cancer effects. The results of epidemiologic studies suggest that high doses of lead may be carcinogenic to humans. Several studies were impacted by a lack of control for confounding factors, and co-exposure to other contaminants.
New Zealand Ministry of Health (NZ MOH)	2012	The Environmental Case Management of Lead-Exposed Persons. Guidelines for Public Health Units.	• BLLs equal to or above 0.48 µmol/L (10 µg/dL) from non-occupational exposures are notifiable to the Medical Officer of Health under the Health Act. • Dust is a major pathway of exposure for lead, with lead-based paint being a significant contributor. • There is evidence of decreases in IQ in children with BLLs less than 10 µg/dL, and also evidence of a lack of reversibility of these effects. However, the NZ management strategy is based on the 10 µg/dL intervention level. At the time, the US CDC had not yet reduced their BLL intervention level to 5 µg/dL.
US National Toxicology Program (NTP)	2012	Health Effects of Low-Level Lead	• The NTP evaluated both grey and primary literature, with a focus on studies evaluating BLLs less than 10 µg/dL. • NTP concluded that there is sufficient evidence that BLLs less than 10 µg/dL are associated with adverse neurodevelopmental effects in children (including attention related behavioural problems and decreased cognitive performance), delayed puberty, and decreased postnatal growth. Sufficient evidence was also found of an association between BLLs less than 5 µg/dL with adverse reproductive effects in adult females and reduced fetal growth.

Table B- 1 Summary of Recent Comprehensive Review Documents Completed by Regulatory Agencies Regarding Lead Exposure and Human Effects

Agency/Organization	Publication Date	Title	Findings
			• There is sufficient evidence of an association of BLLs greater or equal to 15 µg/dL with adverse reproductive effects in adult men, but limited evidence of adverse effects on male fertility with BLLs less than 10 µg/dL. • There is sufficient evidence of an association between BLLs less than 5 µg/dL with decreased kidney function, and BLLs less than 10 µg/dL on increased blood pressure and hypertension. • There is sufficient evidence of an association between essential tremor in adults with BLLs less than 10 µg/dL but a limited association for this effect with BLLs less than 5 µg/dL. • There is limited evidence of an association between maternal BLLs less than 10 µg/dL with spontaneous abortion or stillbirth. • Limited evidence was identified of an association between BLLs less than 5 µg/dL with delayed puberty in children and reduced fetal growth in relation to maternal exposures. • There is inadequate evidence of a relationship between BLLs and birth defects (e.g. congenital malformations), endocrine effects, preterm birth and gestational age, and stillbirth. • There is limited evidence of an association of BLLs less than 10 µg/dL with immunoglobulin immune effects in children, but inadequate evidence of an association in adults. • There is limited evidence of association of adult BLLs less than 10 µg/dL with increased cardiovascular mortality, decreased auditory function, or incidence of amyotrophic lateral sclerosis.
US Environmental Protection Agency (US EPA)	2012	Integrated Science Assessment for Lead (Third External Review Draft)	• The US EPA identified a causal relationship between lead exposure and cognitive function decrements and attention-related behavioural problems in children. At BLLs less than 4 µg/dL, there is no evidence of a threshold for these effects in young children (ages 4 to 11). Increases in attention-related problems were found in populations of children ages 7-17 years or young adults 19-24 years with prenatal cord or lifetime average mean BLLs between 6.8 and 14 µg/dL. • A causal relationship between lead exposure and cancer, hypertension and coronary heart disease were identified, as well as developmental effects and male reproductive function. • The relationships between lead exposure in children and several neurological effects were found to be likely causal in nature and included conduct problems, internalizing behaviours, sensory function decrements, and motor function decrements. • In adults, a likely causal relationship was identified for cognitive function decrements, psychopathological effects, and reduced kidney function. • In both children and adults, the relationship between lead and hematologic effects was found to be causal, while the relationships between lead and atopic and inflammatory effects and decreased host resistance were deemed likely causal. • A classification of *Suggestive of Causal* relationship was identified for sensory function decrements in adults, subclinical atherosclerosis, adverse birth outcomes, and female reproductive effects. • Inadequate evidence of a relationship between lead exposure and neurodegenerative disease or autoimmunity were identified.
US Environmental Protection Agency (US EPA)	2019	Final Rule. Pre-Publication Notice: Review of the Dust-Lead Hazard Standards and the	• Floor dust in homes and child-care facilities are a significant route of exposure to children. • A non-zero value for lead in dust is appropriate at this time given the challenges associated with achieving a zero-concentration level.

Table B- 1 Summary of Recent Comprehensive Review Documents Completed by Regulatory Agencies Regarding Lead Exposure and Human Effects

Agency/Organization	Publication Date	Title	Findings
		Definition of Lead-Based Paint. June 21, 2019.	• The dust-level hazard standard (DLHS) for lead in floor dust is to be reduced from 40 µg/ft2 to 10 µg/ft2, and the DLHS for lead in windowsill dust is reduced from 250 µg/ft^2 to 100 µg/ft2. • These changes are based on internal review by the US EPA in support of this rule change, as well as conclusions reached by other US agencies (ACLPP, CDC, NTP). • The changes in DLHS are anticipated to impact building construction, specialty trade contractors, real estate (property owners), day care services, schools, technical and trade schools (training providers), building inspectors and engineers, governmental agencies that own buildings, federal housing, among others.
World Health Organization (WHO)	2010a	Final Review of Scientific Information on Lead	• The most critical health effects are the incidence of neurodevelopmental effects in children. • Inhalation is a key route of exposure for individuals who live near point sources. • For children, the ingestion of dust and soil are considered to be major pathways. For adults, food and beverages are the primary sources of exposure. • There is no clear threshold level below which lead is not without adverse effects, and also cited WHO's withdrawal of the previous tolerable weekly intake guideline value for lead on the basis that it was no longer adequate against the protection of cognitive effects in children. There is consistent evidence of adverse effects in children down to and below BLLs of 10 µg/dL. • Children and pregnant women represent susceptible populations. • Additional monitoring data is needed to better characterise lead exposure and to mitigate risk.
	2010b	Childhood Lead Poisoning	• Low-level lead exposure in utero and during childhood in association with BLLs less than 10 µg/dL is associated with adverse neurobehavioral effects in children that can persist into adulthood and be irreversible in nature. These effects may occur at BLLs less than 5 µg/dL. These effects place a significant economic burden on families and societies. • The immunological, reproductive, and cardiovascular effects of lead are also apparent at BLLs less than 10 µg/dL. • Socioeconomic factors are important predictors of lead exposure. Socially and economically deprived children have the greater burden of disease in relation to lead, due to higher likelihood of living on contaminated land, in close proximity to point sources, and in substandard housing with lead paint impacts.
	2016	Lead in Drinking Water	• It is estimated that more than 80% of daily lead intake arises from the ingestion of food, dirt, and dust in most areas. • Adverse effects on infant and child development have been associated with BLLs less than 10 µg/dL (range 6 to 9.5 µg/dL). • Lead-associated decrements in IQ may be markers for other neurobehavioural effects (attention deficit hyperactivity disorder, reading delays, executive dysfunction, fine motor deficits). • There is no evidence of a threshold for increased hypertension in association with lead in populations aged 21-55 years with BLLs in the range of 7 to 34 µg/dL. • Chronic nephropathy has not been detected in association with BLLs less than 40 µg/dL.

B-1.2 Available Toxicity Reference Values and Hazard Classifications for Lead

A toxicity reference value (TRV) is a dose of a chemical that is without adverse effect. In general, chemicals may be categorized into two groups based on the characteristics of their toxic responses – threshold and non-threshold. In some instances, chemicals may cause both threshold and non-threshold effects. The concept of a threshold implies that there is a dose above which adverse effects may be observed. For non-threshold chemicals, adverse effects may occur without a clear toxic threshold response due to a lack of a clear dose-response relationship.

The majority of the regulatory agencies included in this review do not currently list TRVs for lead. This is in part due to the evolution in the health effects database of lead, where previously developed TRVs are no longer considered to be applicable, and the body of evidence is under review by regulatory agencies. Also, lead exposure is most effectively evaluated by total exposure from all routes combined (e.g. as assessed by biomarkers) as opposed to route-specific approaches.

Limits developed by agencies and organizations that evaluate workplace and occupational exposures have not been included in this review to permit a focus on information relevant to public health. Further, the discussion is also focused on oral-based values rather than inhalation.

The most recently derived TRV is that arising from a review by Health Canada in support of the revised lead drinking water quality guideline (Health Canada, 2019). Health Canada (2019) states that the lowest BLL associated with adverse neurodevelopmental effects cannot be identified, and as a result, a non-threshold approach using low-dose linear extrapolations should be used. Specifically, Health Canada (2019) identified a benchmark dose (BMD) of 0.4 µg/kg (external oral dose). This value was obtained from PBPK and blood lead modelling completed by the EFSA (2010) as part of an assessment of lead in food. Data from Lanphear *et al*. (2005) were analysed by EFSA (2010) and the BLL associated with a 1% response threshold from BMD analysis was identified as 1.2 µg/dL. This 1% response threshold corresponds to a change in population IQ equal to 1 point (after IQ tests normalized to a mean of 100). The EFSA (2010) then employed blood-lead models and determined that a BLL of 1.2 µg/dL was associated with a daily intake ranging from 0.4 to 0.6 µg/kg bw-day (depending on the model used). Health Canada (2019) notes that it selected the lowest value in the range as a point of departure (POD) for the drinking water guideline derivation, which was based on the US EPA's Integrated Exposure, Uptake, and Biokinetic (IEUBK) model. As a linear extrapolation was used, no uncertainty factors were applied to the POD (Health Canada, 2019).

Table B- 2 Available Non-Carcinogenic Toxicity Reference Values for Lead

Agency	Target Organs/Routes	Risk Estimate	References/Notes
California Office of Health Hazard Assessment	Neurodevelopmental effects	0.5 µg/day	Maximum Allowable Dose Level (MADL). Based on historic occupational value (OEHHA, 2019).
		2.86 µg/day	Level of concern for children based on a change of 1 µg/dL in BLL. Noted to be associated with high level of uncertainty (OEHHA, 2009).

Table B- 2 Available Non-Carcinogenic Toxicity Reference Values for Lead			
Agency	**Target Organs/Routes**	**Risk Estimate**	**References/Notes**
		Exposures predicted by models to result in a 1 µg/dL increase in child BLL	Benchmark developed by Cal OEHHA (2007) for assessment of children at schools. An incremental change in BLL of 1 µg/dL does not necessarily represent a safe level, as it is associated with a decrease in IQ.
Health Canada Water Quality	Neurodevelopmental effects	POD: 0.4 µg/kg-day	Health Canada, 2019
Health Canada Contaminated Sites	Under review	-	-
Other		0.6 µg/kg-day (infants and children) 1.3 µg/kg-day (adults)	SNC Lavalin (2012) for Health Canada. Not official values. If TRVs used for guideline development, an allocation factor of 1 must be used. Intended for site-specific use.
RIVM	Neurodevelopmental effects	1.9 µg/kg-day	RIVM 2017
US EPA	Under review		US EPA 2019
WHO	-	-	Provisional Tolerable Daily Intake Level withdrawn. Drinking Water values based on treatment and analytical achievability. WHO, 2016.

Table B- 3 Available Carcinogenic Classifications and Toxicity Reference Values for Lead				
Agency	**Classification**	**Tumour Sites and Routes**	**Carcinogenic Risk Value Estimate**	**References**
California Office of Environmental Health Hazard Assessment	Carcinogenic under Proposition 65	Kidney tumours, oral route	1.2 µg/kg-bw-day (Risk Specific Dose, 1 in 100,000 ILCR) 15 µg/day (No Significant Risk Level or NSRL)	OEHHA, 2019
Health Canada	Carcinogenic to humans	Kidney tumours	1.5 µg/kg-bw-day (Risk Specific Dose, 1 in 100,000 ILCR)	Health Canada, 2019
International Agency for Research on Cancer (IARC)	Group 2A Probably Carcinogenic to humans (lead) Group B Possibly Carcinogenic to	Kidney, brain tumours; oral route; Soluble and insoluble forms	-	IARC, 2006

Table B- 3 Available Carcinogenic Classifications and Toxicity Reference Values for Lead				
Agency	**Classification**	**Tumour Sites and Routes**	**Carcinogenic Risk Value Estimate**	**References**
	humans (inorganic lead compounds) Not classifiable (Organic lead compounds)			
National Toxicology Program (NTP)	Reasonably anticipated to be human carcinogens (lead and lead compounds)	Limited evidence in humans – lung, stomach and urinary bladder; Occupational exposures Sufficient evidence in animals – kidney, brain, hematopoietic and lung – oral, injection, both soluble and insoluble, organic and inorganic	-	NTP, 2016
United States Environmental Protection Agency (US EPA)	B2 Probable human carcinogen	Inadequate evidence in humans Sufficient evidence in animals – kidney tumours; oral and subcutaneous	Qualitative statement provided, recommending compliance with CDC recommendations	US EPA IRIS, 2004

NV not derived due to challenges in deriving a quantitative risk estimate for lead

B-1.3 Available Soil Quality Guidelines – United States and International

The material in this section is an accompaniment to the text within the main report. A summary of selected soil quality guidelines from the United States and International jurisdictions are presented in Table B- 4 to Table B- 6.

Table B- 4 Soil Quality Guidelines for Lead in the United States for Selected States			
Agency	**Value**	**Basis**	**Reference**
California DTSC	• 80 µg/g (residential) • 320 µg/g (industrial)	Represent lead concentrations in soil that would result in a 90th percentile estimate of a 1 µg/dl incremental increase in BLL in children or adult pregnant workers, respectively. Intended for comparison with 95% upper confidence level on the mean (UCLM).	CDTSC, 2019; Based on assumption that hot spots or outliers are not present. If they are, they must be assessed separately.

Table B- 4 Soil Quality Guidelines for Lead in the United States for Selected States

Agency	Value	Basis	Reference
Massachusetts DEQ	• 200 µg/g (residential and non-residential)	Direct contact; at or within 500 feet of a residential dwelling, residentially-zoned property, school, playground, recreational area or park.	Mass DEQ, 2017
Michigan DEQ	• 40 µg/g (residential clean-up) • 90 µg/g (non-residential clean-up)	Direct contact. Residential value protective of prenatal and postnatal exposure, and a blood lead level of 5 µg/dL. Non-residential value protective of pregnant adult in workplace.	MDEQ, 2018
Missouri DNR	• 260 µg/g (residential) • 660 µg/g	Direct contact. Based on IEUBK and Adult Lead Methodology (ALM) modelling and a BLL of <10 µg/dL.	MDNR, 2006
Mississippi DEQ	• 400 µg/g (unrestricted) • 1,500 µg/g (restricted)	Direct contact. Recommends use of ALM and IEUBK.	Miss DEQ, 2002
New York DEC	• 63 µg/g (unrestricted land use) • 400 µg/g (residential) • 1,000 µg/g (commercial) • 3,900 µg/g (industrial)	Unrestricted use value is based on rural background concentrations.	NYDEC, 2010; Thomson Reuters, 2019
New Jersey DEP	• 400 µg/g (residential) • 800 µg/g (non-residential)	Direct contact. Recommends use of ALM and IEUBK.	Gov NJ, 2017
Illinois EPA	• 20.9 µg/g (background objective, non-metropolitan) • 36.0 µg/g (background objective: metropolitan areas) • 400 µg/g (Remediation criteria: residential, construction, industrial, commercial)	Based on US EPA Soil Screening Level (SSL).	IPEA, 2001; 2019
Ohio EPA	• 400 µg/g (residential) • 750 µg/g (construction and excavation) • 1,800 (commercial, industrial)	Based on US EPA SSL.	OEPA, 2014
Pennsylvania DEP	• 500 µg/g (residential) • 1,000 µg/g (non-residential, 0 – 2 ft below ground level (bgl) • 190,000 µg/g (non-residential, 2-15 ft bgl)	Residential value based on IEUBK modelling and applies down to 15 ft bgl. Non-residential shallow value based on a model developed by the Society for Environmental Geochemistry and Health(SEGH model), and the deep non-residential value represents a cap.	PADEP, 2018
Texas CEQ	• 500 µg/g (residential, 0.5 and 30 acre source areas) • 1,600 µg/g (commercial, 0.5 and 30 acre source areas)	Includes ingestion, inhalation, dermal and vegetable consumption.	TCEQ, 2018

Table B- 4 Soil Quality Guidelines for Lead in the United States for Selected States

Agency	Value	Basis	Reference
US EPA	• 400 µg/g (Soil Screening Value, residential)*	Based on evidence of developmental nervous effects in the 2 to 8 µg/dL range	US EPA 2016, 2019
Washington DOE	• 250 mg/mg (unrestricted land use) • 1,000 µg/g (industrial)	-	WDOE, 2015

*US EPA (2016) memorandum recommends that site-specific values be developed on an as needed basis using the IEUBK and/or ALM models as appropriate, and incorporate bioaccessibility testing for lead using established methods.
DTSC: Department of Toxic Substances Control; CEQ: Commission on Environmental Quality; DEQ: Department of Environmental Quality; DNR: Department of Natural Resources; DEC: Department of Environmental Conservation;

Table B- 5 Soil Quality Guidelines for Lead – Australia and New Zealand

Agency	Value	Basis	Reference
Australia NEPC	• 300 µg/g (low-density residential) • 1,200 µg/g (high-density residential) • 600 µg/g (recreational) • 1,500 µg/g (commercial, industrial)	Health-based investigation levels for soils to a depth of 3 metres below ground level (mbgl). Based on total lead intake where 95% of the population has a BLL less than 10 µg/L. Values under review.	NEPC, 2014, NEPC, 2010
New Zealand MOE	• 300 µg/g (residential) • 400 µg/g (residential screening level) • 1,200 µg/g (high-density residential) • 600 µg/g (recreational) • 1,500 µg/g (commercial, industrial)	Based on Australia NPEC guidelines and US EPA SLL.	NZ MOE, 2013
New Zealand MOH	• 160 µg/g (rural residential) • 210 µg/g (urban residential) • 500 µg/g (high-density residential) • 880 µg/g (recreational) • 3300 µg/g (commercial/industrial)	Risk-based. Assumed 25% produce consumption.	NZ MOH, 2012

Table B- 6 Soil Quality Guidelines for Lead – Europe

Country	Soil Value	Basis	Reference
Austria	• 100 µg/g (residential, warning SSL) • 500 µg/g (residential, unacceptable risk)	Cannot be readily determined. Due to non-English information, reliance was placed on a review by EC JRC 2007.	EC JRC, 2007
Belgium (Bruxelles)	• 700 µg/g (residential)		
Belgium (Flanders)	• 700 µg/g (residential)		EC JRC, 2007
Belgium (Walloon)	• 195 µg/g (residential, warning SSL) • 700 µg/g (residential, unacceptable risk)		EC JRC, 2007
Czech Republic	• 250 µg/g (residential, warning SSL) • 300 µg/g (residential, unacceptable risk)		EC JRC, 2007
Denmark	• 40 µg/g (residential, warning SSL) • 400 µg/g (residential, unacceptable risk)		EC JRC, 2007
Finland	• 60 µg/g (residential, warning SSL) • 200 µg/g (residential, unacceptable risk)		EC JRC, 2007
Germany	• 400 µg/g (residential, warning SSL)		EC JRC, 2007
Italy	• 100 µg/g (residential, unacceptable risk)		EC JRC, 2007
Lithuania	• 100 µg/g (residential, unacceptable risk)		EC JRC, 2007
Netherlands	• 530 µg/g (residential, unacceptable risk) • 800 µg/g (residential with garden use)	The difference between the two values is not clear from the documentation available in English. The 800 µg/g value is based on a TRV of 1.9 ug/kg-bw per day.	EC JRC, 2007 RIVM, 2017
Poland	• 150 µg/g (residential, unacceptable risk)		EC JRC, 2007
Slovakia	• 150 µg/g (residential, warning SSL)		EC JRC, 2007
Sweden	• 300 µg/g (residential, warning SSL)		EC JRC, 2007
United Kingdom	• 80 µg/g (allotments/community gardens) • 200 µg/g (residential, with home produce consumption) • 310 µg/g (residential, no home produce)	Based on probabilistic modelling that incorporated different exposure parameters, different BLLs (1.6, 3.5 and 5 µg/dL), and different blood lead models (IEUBK, ALM, Carlisle	UK DEFRA, 2014a,b

Table B- 6 Soil Quality Guidelines for Lead – Europe			
Country	**Soil Value**	**Basis**	**Reference**
	• 630 (Parks/open spaces, tracking distance to residential) • 1,300 µg/g (parks/open spaces, negligible tracking to residential) • 2,300 µg/g (commercial)	and Wade). A BLL of 3.5 µg/dL was selected as being the most defensible.	

B-1.4 Lead in Soils and Gardens – Additional Information on Management Strategies

Toronto Public Health (TPH) (2011, 2012) has developed guidance for assessing soils within urban gardens (including allotment gardens where parcels are cultivated individually, and community gardens where the entire area is tended to collectively by a group of people). Their approach consists of four steps: establishing a level of concern, sampling and testing of soil, interpretation of soil results using certain soil screening values, and risk mitigation. The level of concern of the site (low, medium, high) is based on the findings of a site visit and a review of site history (current and past use, any requirements necessary under existing contaminated site frameworks). Where the level of concern is medium, or a garden of more than 16 m^2 (170 ft^2) is planned, soil testing is recommended by TPH. Such testing is not recommended for smaller gardens due to limited cost effectiveness. The soil depth of relevance to gardening is down to 40 cm. TPH recommends two different sampling strategies for allotments vs. community gardens:

- For allotment gardens, for every 10 by 10 metre area, nine individual samples should be taken in an 'X' or 'Z' pattern, and then combined into one composite sample.
- For community gardens (where gardeners have unrestricted movement), nine samples should be taken in an 'X' or 'Z' pattern for every 15 by 15 metres of land, and then combined into one composite sample.

TPH developed a short-list of common soil contaminants, and then derived urban gardening soil screening values and a risk management framework based on the concentration in soil relative to these screening values. The screening values presented within TPH (2011) are intended to be protective of human health (including children), reasonably worst-case, for use in the City of Toronto, and inclusive of other sources of exposure to soil contaminants (e.g. other than garden produce alone) (TPH, 2012). For lead, the two screening values are 34 µg/g and 340 µg/g. Within the TPH framework for urban soils, this indicates that for soils with lead concentrations less than 34 µg/g, only good gardening practices are recommended (hand washing, produce washing). However, if soil lead concentrations are between 34 µg/g and 340 µg/g, then a level of exposure reduction is recommended, including the following actions (in addition to good hygiene):

- Dilution of soil concentration through the addition of clean soil and organic matter (i.e. compost, manure);
- Lowering the bioavailability of contaminants through soil additions;
- Reducing dust migration by covering bare soil with ground covers or mulch;
- Peeling of root vegetables before eating and cooking; and,

- Avoiding or reducing crops that can accumulate contaminants[1].

At soil concentrations above 340 µg/g, it is recommended that in addition to good hygiene practices and dust reduction measures, that exposure pathways *via* garden produce be eliminated through the construction of raised bed gardens or containers with the addition of clean soil and organic matter on a regular basis, or restricting crop types to only nut and fruit trees (TPH, 2011).

The US EPA (2014) has developed guidance regarding the sampling and management of garden soils containing lead. This guidance is based on the soil standard in the US being 400 µg/g for lead in residential soils, and it is noted that this value may not be adequate for intensive gardening and a high level of consumption of home produce. In addition to the review completed by US EPA (2014), a spreadsheet model was developed that includes calculations for garden produce exposure in lead contaminated soils. The lowest soil lead concentration in Table B- 7 (100 µg/g) that is associated with potential risk is lower than the US EPA SSL of 400 µg/g due to differences in the assumptions regarding garden produce consumption.

Table B- 7 Recommended Guidelines for Lead in Garden Soil (US EPA, 2014)

Soil Lead Concentration	Recommended Actions
• < 100 µg/g	Low risk for gardening. No remedial action needed. Good gardening and hygiene practices suggested. No restrictions on crop types.
• >100 to 1200 µg/g	Potential risk. Relocate garden to lower risk areas, increase use of soil amendments, barriers, use raised beds or containers. Use gloves and tools in addition to good hygiene. Replace root vegetables with fruiting vegetables, vines and trees. Increase the use of soil amendments (compost, clean fill, mulch) and other remedial measures.
• >1200 µg/g	All of the above noted good hygiene and gardening practices. Recommend excavation of impacted soil or garden relocation, and use of raised beds or containers. Relocate garden. Restrict child access to impacted soils. Select plants with shallow roots to help limit access of plant roots to impacted soil. Plants with shallow roots for raised beds or areas with replacement soil to ensure that roots do not reach the lead contaminated soil.

The New Zealand Ministry of Health (NZ MOH) has developed a protocol for lead sampling in various media in relation to environmental case management. While home-grown produce may contribute to overall lead exposure, this is noted to be minor compared to the risks associated with the ingestion of dusts and soil (NZ MOH, 2012).

With respect to soil sampling, it is recommended that samples be collected from the following areas:

- Outdoor play areas
- Sand pit/sand box

[1] Plant types that accumulate contaminants are not well defined within TPH (2011)

- Vegetable garden
- Areas of soil readily tracked into house
- Areas most likely to be contaminated (e.g. lead paint hot spots)
- Bare soil within one metre of lead-painted surfaces and areas from current or past renovation
- Dusts from paths, patios, or concrete strips adjacent to the house (particularly if located adjacent to past or present led-based paint hazards)

Hot spots of lead contamination in soils typically occur within 1 to 2 metres of the painted surface, although past dumping or burning of building materials containing lead-based paints can occur at distances from the structure. Exterior dusts may also be impacted with lead from these sources (NZ MOH, 2012).

The NZ MOH (2012) recommends that multiple samples should be collected for each location and made into a composite. Unless core samples are taken and analyzed, all samples should be taken from the top 3 to 5 cm of soil. However, older soil layers of lead may be buried beneath the top 5 cm of lead. It is recommended that core samples be checked for lead variability at various depths (NZ MOH, 2012).

The number of compositive samples should be relative to the area being sampled (guidelines provided in Table B- 8.

Table B- 8 New Zealand Soil Sampling Guidelines Regarding Composite Samples from Surface Soils (3-5 cm depth)

Potentially Impacted Surface Area (m^2)	Number of Samples in Composite
5	3
10	5
30	8
50	12

B-2.0 BLOOD LEAD AND PUBLIC HEALTH, COMMUNICATIONS AND MANAGEMENT

The material within this section is intended to supplement the information within Section 4.3 of the report.

As noted in the main report, in December 2018, the United States issued an Executive Order accompanied by an action plan regarding the reduction of childhood lead exposures and associated health impacts (US Gov, 2018). It is intended to serve as a 'blueprint' for exposure reduction and requires collaboration between all levels of government as well as property owners, businesses and parents. The action plan document was authored by a Presidential Task Force following an in-depth stakeholder consultation effort. Four primary goals were set by the Task Force:

- Reduce children's exposure to lead sources – with a focus on reducing lead-based paint hazards, re-evaluating the dust-lead standards, and financial support for renovation and remediation projects; reducing exposure through drinking water through improved regulation of lead-free plumbing products, enhanced testing and management of lead in drinking water in schools and daycares, and funding for infrastructure to remove lead-containing features; reduction of lead exposure in soil – continued monitoring to identify and remove lead-impacted soils for the protection of sensitive community residents, public education regarding safer gardening practices; reduction of lead in ambient air – continued evaluation of lead emissions from aircraft and other emission sources and provision of funding for further research into lead-free aircraft emissions; reduction of lead from occupational sources, cosmetics and personal care products.
- Identify lead-exposed children and improve their health outcomes through improved surveillance of children, identify high-risk children through screening surveys or targeted prevalence studies, and improve access to testing and educational materials at various levels of government (including indigenous children); improved blood-lead follow up testing; and facilitate screening for developmental delays in children identified as being at-risk;
- Communicate more effectively with stakeholders, promoting lead prevention and monitoring education, availability of more resources to families and public health agencies, streamlined federal funding and consistent messaging regarding lead risks;
- Support and conduct critical research to inform efforts to reduce lead exposures and related health risks, reduce duplication and enhance programs through coordination and collaboration; generation of data mapping tools to aid in prioritization efforts; generate research data to identify critical gaps in exposure/risk analysis.

Following the implementation of the reduced intervention level for blood lead and a recall of testing devices known as LeadCare® by the US Food and Drug Administration, a series of interviews were completed by Trinh and Mason (2019) evaluating blood lead testing and follow up with 9 different State agencies. Several challenges associated with blood lead data tracking were reported by these agencies, including missing contact information (including a transient population that was hard to follow-up with) for test subjects that would permit prompt follow-up, missing information regarding sample type (venous or capillary), lack of information to identify pregnant and lactating women, details regarding laboratory status and analysis, and missing data points (Trinh and Mason, 2019). Despite these shortcomings, the overall implementation of the CDC framework has been positively received. However, the CDC is not a formal regulatory

agency with enforcement authority, so it is not clear how widely and consistently the blood lead recommendations have been implemented (Trinh and Mason, 2019).
In Washington State, the Governor recently made a Directive to the Department of Health, based on a recognizance of there being no safe level of lead exposure:

- Transition the Child Blood Lead Registry from a paper-based system to a fully electronic reporting system;
- Assess funding needs of local public health programs so that lead investigations and remediation work can be completed in households where children with elevated BLLs have been identified;
- Evaluate the need for policy changes that would require schools and childcare providers to evaluate sources of lead exposure in facilities; and,
- Prioritize the removal of lead in water distribution systems (WSDOH, 2016a).

The State of Washington has developed the Washington Tracking Network (WTN), which is a public website where information regarding environmental health hazards can be searched by location and is searchable by map at the community level. However, for lead, only risks from housing and socioeconomic status (poverty) were available to evaluate exposure potential (WSDOH, 2016b). As of October 2018, it is recommended by the WSDOH that all healthcare providers educate the parents of children ages 6-months to 6-years regarding lead guidance during routine check-ups, and should complete blood lead testing at 12- and 24-months of age based on risk level as determined by the following factors:

- Lives in or regularly visits residence built before 1950 (that has not undergone lead abatement or tested negative after remodelling);
- Lives in or regularly visits residence built before 1978 that has recent or ongoing renovations/remodelling;
- Is from a low-income family (e.g. less than 130% poverty level);
- Has a sibling or frequent playmate with elevated blood lead (BLL greater than 5 µg/dL);
- Is a recent immigrant, refugee, foreign adoptee or a child in foster care;
- Has a parent or caregiver who works professionally (remodelling or demolition, painting, work or visit gun range, mining smelting or battery recycling, making lead fish weights or ammunition) or recreationally (pottery or porcelain with lead glaze, stained glass) (WSDOH, 2018).

Where the answer to any of the above questions is yes, or is unknown, blood lead testing should be completed. Testing might also be recommended if parents have concerns, children live within a kilometer of an airport or lead-emitting industry or orchard, a child has pica behaviour, or is affected by neurodevelopmental disabilities (such as autism, attention-deficit hyperactivity disorder or learning delays) (WSDOH, 2018). Follow-up testing is recommended after 1-year of the first test for children with BLLs less than 5 µg/dL, within one to three months if the first result is between 5 and 14 µg/dL, within one to four weeks if between 15 to 44 µg/dL, and within 48-hours if greater than 45 µg/dL (WSDOH). Venous samples are preferred over capillary samples, unless adequate care is taken to clean and prepare the finger before testing. Initial samples that are capillary should be followed up with venous samples (WSDOH, 2018).

B-3.0 REFERENCES

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APPENDIX C

Detailed Summary Tables for Identified Studies from Literature

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C-1. INTRODUCTION

This Appendix is intended to supplement the information provided within Task 4 of the main report. Table C- 1, Table C- 2, and Table C- 3 includes detailed summaries for literature discussing soil lead concentrations in urban areas, near industrial point sources and literature with soil and/or blood bead levels (BLL) in urban and industrial areas, respectively.

Table C-1 Soil Lead Concentrations in Urban Areas				
Source, location	**Sample number/depth**	**Lead concentrations**	**Notes**	**Reference**
Residential areas within and outside Lubbock, Texas	N=52 soil samples collected from 1-2 cm depth, street-side properties and away from buildings Samples collected along 3 different transects through city	All transects: mean 41.8 µg/g, median 35.4 µg/g Transect 1 – city centre core through residential (n=28): median 35.4 µg/g, range 3.9 to 98.8 µg/g. Transect 2 – along major thoroughfare originating in city centre, mixed residential/commercial (n=13): median 33.5 µg/g; range 2.8 to 174.2 µg/g Transect 3 – originating city centre through mixed residential/commercial (n=11). Median 38.7 µg/g, range 9.5 to 89.0 µg/g Supplementary rural samples extended Transect 1 (n=5), mean 4.9 µg/g.	• Care was taken during sampling to avoid areas that could be affected by lead-paint. Elevated concentrations in city centre attributed by authors to leaded gasoline impacts. More distant sites generally built after lead fuel phase-out complete in 1986. • Median city centre lead concentrations from the 3 transects similar – 35.4, 33.5 and 38.7 µg/g	(Brown et al. 2008)
Public areas, urban Chicago and rural Illinois	Urban Chicago: N=57 Sample depth: 0-15 cm Regional agricultural soils (within 500 km): sample depth 20 cm	Urban Chicago: mean 395 µg/g, Median 198 µg/g Regional agricultural soils: median 15 µg/g	• Urban concentrations of lead were 13-times higher than regional concentrations in samples collected in rural areas. • Mutual correlations observed in concentrations of lead, zinc, copper and nickel. • Authors note that sources are most likely the result of airborne deposition from vehicle and roadway sources, and possible fossil fuel combustion, waste incineration and steel production. • The sample density (1 site per 10 square kilometres) was noted as being inadequate for determining the distribution of the metals across the city.	(Cannon and Horton 2009)
Residential and public areas, Gainesville and Miami, Florida	N=200 samples (60 residential, 60 commercial, 60 parks, 60 public buildings), Sample Depth: 0-20 cm (Gainesville)	Miami (overall): median 98 µg/g Miami, Residential Median 121 µg/g, mean 161 µg/g, geometric mean 120 µg/g	• Gainesville (pop. 95,000) and Miami (pop 370,000) were selected to compare two urban areas of similar size but with different populations and industrial activities. The soils in the two areas are different with respect to soil layer types and composition.	(Chirenje et al. 2004)

Table C-1 Soil Lead Concentrations in Urban Areas

Source, location	Sample number/depth	Lead concentrations	Notes	Reference
	N=240 samples, Sample Depth: 0-10 cm (Miami)	Miami, Public Parks Median 82 µg/g, mean 107 µg/g, geometric mean 78.8 µg/g Gainesville (overall) Median 15 µg/g Gainesville, Residential Median 20.4 µg/g, mean 66.9 µg/g, geometric mean 22.6 µg/g Gainesville, Public Parks Median 7.23 µg/g, mean 43.5 µg/g, geometric mean 9.97 µg/g	• Residential, commercial and public land samples collected. • Both residential and commercial areas were found to have higher concentrations of lead than public parks.	
Playgrounds, Madrid, Spain	N=40 surface soil samples (2 from 20 municipal playgrounds) Soils collected from a depth of 1-2 cm	2002 sampling: Median 35 µg/g, 95UCLM 43 µg/g, mean 38 µg/g, range 10-106 µg/g 2003 sampling: Median 17 µg/g, mean 22 µg/g, range 6.1 to 65 µg/g	• The lead concentrations in the surface soil may have been impacted by the periodic (approximately every 4 years) replacement of gravel material in the playgrounds. • Authors compared data to studies of parks in other areas and historical Madrid data. The regional background mean lead soil concentration was noted to be 17 µg/g (range 3.1 to 291 µg/g).	(De Miguel et al. 2007)
Residential playground soil, metropolitan areas, France	N=315 samples	Median: 27 µg/g, range 1.3 to 3,408 µg/g	• Dust (exterior and interior also collected) • Authors state that the results are comparable to other countries.	(Glorennec et al. 2012)
Urban and peri-urban (unimpacted) soils, State of Sonora, Mexico	N=10 (urban, including play areas) N=5 (peri-urban) Yellow traffic paint also sampled (n=11) All samples 0-5 cm topsoil.	Urban: Median: 42.5 µg/g, range 34-173 µg/g Residential streets: median 26 µg/g Peri-urban: 25-32 µg/g (range) Yellow paint:	• Lead gastric bioaccessibility ranged between 40.8 to 50.8%, and the authors note that this might be attributable to acid rebound and subsequent metal release. • Kaolinite may enhance lead bioaccessibility in the gastric environment, but further study is needed. • Soil mineral composition can influence lead bioaccessibility in gastric and intestinal environments.	(González-Grijalva et al. 2019)

Table C-1 Soil Lead Concentrations in Urban Areas

Source, location	Sample number/depth	Lead concentrations	Notes	Reference
		31,958 µg/g		
Samples collected from international roadway (E30 that connects Ireland with Russia) within central-East Poland during 2015.	N=96 Soil samples collected 1,5,10 and 15 metres from expressway	10.37 µg/g (average, all distances) 13.52 µg/g (maximum)	• Lowest soil lead concentrations located 1 m from roadway, and highest 5 m from roadway. Concentrations at 10 and 15 m from roadway comparable to mean. • Lead content in aboveground plants varied, but was somewhat associated with distance from road and grass species. Highest measured lead concentration was 6.896 µg/g.	(Jankowski et al. 2019)
Terre Haute, Indiana	N= 1061 soil samples collected from the Indiana State University Community Garden (1.25 hectare area) located on previous residential land. Depth not clear but noted as top several inches.	Background samples: 0 to 50 µg/g Range: 0 to >600 µg/g (detailed data not provided)	• Area has a history of high traffic volumes and industrial activity, and a high (40%) proportion of pre-1950s housing. • Elevated lead concentrations (400 µg/g) identify in northern portion of garden, located adjacent to an alley. Lead concentrations near roadways (to the west and south) were found to be lower. • Southern portion garden is older and had been amended will fill material.	(Latimer et al. 2016)
Playground soils, Athens, Greece	N=70 samples (0-5 cm depth) collected from 70 playgrounds Samples represent composite of 3 subsamples collected away from fences, equipment and structures.	Soil lead (total): Mean 110.3 µg/g, median 101.3 µg/g, range 59.7 to 289.6 µg/g Available lead*: Mean 5.8 µg/g, median 5.0 µg/g, range, 1.2 to 19.7 µg/g *Available lead calculated based on clay and organic matter composition of soil	• Soil lead concentrations (median and 90th percentiles indicate that at 40% of the playgrounds, target soil values are exceeded but levels are below remediation levels. • Authors note that copper, lead and zinc distribution within the samples was clustered, and all of these metals have been linked to the abrasion and corrosion of brake linings, metals, and alloys in vehicles and machinery. Lead has also been associated with vehicle emissions. • No correlation between the estimated available lead in soil with clay or organic matter was identified. • Authors conclude the lead in Athens was attributable to various anthropogenic activities.	(Massas et al. 2010)
Public areas, Cleveland, Ohio	N=50 surface soil samples	Mean 193.62 µg/g , median 145.5 µg/g, Range 19 to 811 µg/g	• Soli sampling locations selected in common (public) areas located near known brownfields but	(Petersen et al. 2006)

Table C-1 Soil Lead Concentrations in Urban Areas				
Source, location	**Sample number/depth**	**Lead concentrations**	**Notes**	**Reference**
			that showed no evidence of being previously used for commercial or industrial activities. • Soils determined to have heavy metal burdens above naturally occurring levels in Ohio, particularly lead and cadmium.	
Public areas, Cleveland, Ohio	N=50 surface soil samples	Mean 193.62 µg/g , median 145.5 µg/g, Range 19 to 811 µg/g	• 48/144 soil samples (33%) exceeded the Polish guideline of 200 µg/g lead in soil. • The samples from Sosnowiec contained higher lead concentrations than Bytom. • Limited information regarding exposure sources other than urban/industrial provided.	(Piekut et al. 2019)
Residential areas, Ottawa, Ontario	50 residences from within 10 different zones of Ottawa were selected at random N=50 garden soil samples collected (0-5 cm). Composite samples from yard, 5-10 m from house. N=50 house dust samples N=50 street dust samples collected adjacent to residences	Soil lead: Mean 64.69 µg/g, geomean 42 µg/g, median 33.78 µg/g, range 15.6 to 547.44 µg/g Household dust: Mean 405.56 µg/g, geomean 233 µg/g, range 50.20 to 3225.66 µg/g Street dust: Mean 39.05 µg/g , geomean 33.49 µg/g, median 32.93 µg/g, range 12.63 to 122.35 µg/g.	• The 90th percentile of natural lead concentrations are noted by the authors to be 28 µg/g. • Three residences identified as having soil lead concentrations greater than the Ontario criteria (at the time) of 200 µg/g, and all three were located in older neighbourhoods. • Higher dust concentrations were generally found in older homes. • Dust concentrations about 5-times soil concentrations • Authors conclude that only 2-4% of total daily lead exposure is associated with the ingestion of exterior soil. • Dust lead concentrations generally tend to be higher in electrically-heated homes than gas-heated or oil-heated homes. The authors suspect that this may be due to differences in the uses of filters and air circulation. • House dust samples found to contain significantly more lead than soil or street dust. • Housing age ranged from 1893 to 1987, with 27% of the residences built before 1946.	(Rasmussen et al. 2001)
Residential garden soils, Connecticut	N=174 composite samples, from 25 different community gardens in 10 cities and towns between 2004-2007	Community Gardens: Mean 330 µg/g, median 176 µg/g, Range < 10 – 3,490 µg/g Farm soil: Mean 16 µg/g	• Approximately 36% of the gardens sampled in this study had at least one sample with lead concentrations greater than the state guideline of 400 µg/g. • The use of raised garden beds and the addition of physical barriers such as mulch on top of heavy duty porous landscape fabric were shown to be effective.	(Stilwell et al. 2008.)

Table C-1 Soil Lead Concentrations in Urban Areas

Source, location	Sample number/depth	Lead concentrations	Notes	Reference
	Soils from locations on a local farm were collected and also compared.			
Residential and parklands, South Central Los Angeles County, California	N=550 randomly selected locations from grid	Median (total) 81 µg/g Residential samples (near freeway): median 112 µg/g Residential (near arterial roads): median 98 µg/g Residential (general): 40 µg/g Parkland/open areas: median 20.4 µg/g	• Both total and bioavailable lead concentrations were significantly higher near freeways and major arterial roads. • Age of land parcels and traffic variables were important predictors of soil lead. • Road length of freeways within 750 of soil locations explained 28% of variation in bioavailable lead in parks and open areas. • Map of spatial distributions created for Los Angeles area to use as a screening tool for the evaluation of lead exposure in children.	(Wu et al. 2010)
Urban soils, Baltimore, Maryland	N=122 Sample depth: 0-10 cm	Median 89.3 µg/g, range 30.2 to 5,650 µg/g Median background: 60.5 µg/g	• A stratified random sampling design incorporating consideration of land use and cover were considered. Data was right skewed with most data to the left. • About 10% of the soil plots were found to exceed the US EPA guideline of 400 µg/g. • Distinct relationship between levels of heavy metals and distance to major roads in Baltimore (within 100 m). • Lead, copper and zinc were found to be elevated within 100 m of major roads in the city. • Lead and zinc also found to be higher in residential soil from older residential properties. • Authors concluded that a substantial number of areas in Baltimore are contaminated with lead at levels of concern to human health.	(Yesilonis et al. 2008)
Urban outdoor dust, Jilin, China	N=21 Samples collected within 0.5 m of road curb or edge with brush sweeping to collect surface particles	Urban lead dust concentrations: mean 75.60 µg/kg; range 36.42 to 339.51 µg/kg. Background lead for Jilin Province: 28.8 µg/kg	• Industrial areas in the north had significantly higher lead concentrations than the south.	(Yu et al. 2017)

Table C-2 Soil Lead Concentrations Near Industrial Point Sources

Source, location	Sample number/depth	Lead concentrations	Notes	Reference
Agricultural areas and villages near Tin-Tungsten mine, Portugal	N=54 soil (rooting depth) N=40 road dust	Soils 26 to 62 µg/g (range of means) 12 to 146 µg/g (overall range) Road dusts 15 to 46 µg/g (range of means) 6 to 153 µg/g (overall range)	• Lead was detected in the leaves of agricultural plants sampled in the order of lettuce>cabbage>potatoes. • Risk assessment concluded that residents receiving some heavy metal exposures from vegetables.	(Ávila et al. 2017)
Areas near historical and current foundries (23), highways and railroads, Anniston, Alabama	US EPA Database of N=9,365 sample locations from 2000 to 2008; Samples from upper 3 inches of soil US Census data was incorporated into the model to evaluate sociodemographic factors	Soil data statistics not presented (only figures available)	• Data was left skewed with majority of soil concentrations less than 100 µg/g. • Spatial modelling determined that for each 100 metre increase in distance from one of the foundries, a decrease of 2.65% in soil lead was evident. • Coal burning and diesel exhaust from railroads also sources. For each 100 metre increase in the distance from the railroads, a 3.6% decrease in soil lead was evident. • Elevated soil lead concentrations (> 400 µg/g) significantly associated with proximity to known lead emission sources (foundry and major railroads), residential areas with high proportion of older housing, lower occupancy rates, and high percentage of racial/ethnic minorities. • Soil physical properties (gravelly loam, elevation) were significantly associated with elevated soil lead.	(Ha et al. 2016)
Agricultural areas within 4 km radius of an active, large lead and zinc smelter, ZhouZhou, China	8 sampling areas in agricultural areas identified. One control location 15.5 km north of smelter. N=52 vegetable samples (10 common types: Chinese white cabbage, white radish, cauliflower, Chinese cabbage, carrot, leek, cabbage, celery, garlic sprout and lettuce.	Soil concentrations: Closest sampling area to smelter (0.2 km): 953 µg/g. 184 µg/g (control) Edible plant concentrations: Leafy plants (n=28, < 4 km from smelter), mean 1.079 µg/g FW; range 0.185 – 3.714 µg/g FW. Leafy plants (n=4, control): mean 0.106 µg/g FW; range 0.060 to 0.150 µg/g) Non-leafy plants: (n=18, < 4 km from smelter). Mean 0.562 µg/g FW; range 0.042-2.483 µg/g FW	• Limited details regarding soil data provided • The standards for lead in food in China are 0.3 µg/g in leafy vegetables and 0.1 mg.kg FW in non-leafy vegetables. • Average concentrations in contaminated areas for both leafy and non-leafy vegetables were above the food standards for lead. Control samples below food standards. • Estimated daily lead intakes from vegetable consumption: 6.103 µg/kg-day for adults and 5.230 µg/kg-day for children in area < 4 km from smelter. • Estimated daily lead intakes from vegetable consumption in control area: 0.626 µg/kg-day for adults and 0.537 µg/kg-day for children.	(Li et al. 2018)

Table C-2 Soil Lead Concentrations Near Industrial Point Sources				
Source, location	**Sample number/depth**	**Lead concentrations**	**Notes**	**Reference**
		Non-leafy plants: (n=2, control): mean 0.057 µg/g FW; range 0.052 – 0.062 µg/g FW.		
Soil and vegetables near former chemical manufacturing facility, Tamaveni, Romania	N=35 soil samples (24 residential, 9 garden soil, 2 near former industry site) N=12 vegetable samples (6 lettuce, 5 green onion, 1 garlic) from residences	Soil lead: mean 78.1 µg/g; median 53.2 µg/g; geomean 60.1 µg/g; Range 25.4 – 559.5 µg/g Lettuce: mean 1.8 µg/g DW Green onion: mean 0.4 µg/g DW Total vegetables: mean 2.2 µg/g FW	• Lifetime Average Daily Dose (LADD) for lead from 5different residences estimated to range from 4.29E-06 µg/g-day to 8.8E-06 µg/g-day. • Soil concentrations observed to be higher closer to the former chemical plant, deceasing with distance.	(Mihaileanu et al. 2018)
Urban allotment soil in historical contaminated area, Sheffield, United Kingdom	10 allotment (garden) plots tested in triplicate, n=30 samples Onion samples also taken in triplicate from soil plots, n=30 Sample depth up to 20 cm.	Soil lead concentrations were > 200 µg/g in most soils sampled. Well Community Allotments: mean 531.33 µg/g Brightside Gardens: range of means- 241.67 to 430.33 µg/g Oughtibridge Allotments: range of means 138.33 to 200.67 µg/g Handsworth and Richmond Allotments: range of means – 186.00 to 438.67 µg/g	• Lead rolling mill and smelter previously in operation in area where homes are now located • Lead concentrations in onion samples generally below FAO/WHO maximum level for lead of 0.10 µg/g. When risks to health assessed quantitatively, onion consumption was not a significant exposure pathway.	(Weber et al. 2019)

Table C-3 Studies with Soil and/or BLL, Urban and Industrial Areas				
Source, location	**Sample number/depth**	**Lead concentrations**	**Notes**	**Reference**
Surface soil samples from residential yard play areas (bare and vegetated), inner-Philadelphia	N=38 samples, top 0.5 inch (approx. 1.3 cm depth) N=49 children with BLL determined (from same 38 residences)	Total lead concentrations: 659 µg/g (median) 58 to 2821 µg/g (range) Bioaccessible lead concentrations: 681 µg/g (median) 47 to 2567 µg/g (range) Bioaccessibility of soils in study ranged from 66 to 109% of total lead. BLL: Mean 3 µg/dL; median 1.8 µg/dL, range 0.3 to 9.8 µg/dL,	• Some residences were in the vicinity of a historical paint manufacturing facility • 28 of the 38 samples had total soil lead concentrations > 400 µg/g (US EPA screening level) • Statistically significant and positive relationship identified between BLL and soil lead concentration (both total and bioaccessible). Bioaccessibility differences corresponded with BLL variability • Authors suggest that for every 1000 µg/g increase in bioaccessible lead, there is an increase of 1.3 to 1.5 µg/dL in BLL. • No relationship between age, soil lead and BLL was identified.	(Bradham et al. 2017)
Residential soils, from areas at varying distances from five historical smelter operations in Pueblo (now Bessemer) Colorado	Samples collected from middle of front year and/or background of 31 houses w bare soil or vegetation. Depth: 0-5 cm	126 µg/g (median, all zones) 12 to 10,011 µg/g (range all zones) Zone 1 (within 0.75 km radius of smelter sites, soil lead >200 µg/g). Zone 1 child BLL: • < 3.3 µg/dL (n=25, 69.4%) • 3.3 to 4.9 µg/dL (n=6 16.7%) • >5 µg/dL (n=5, 13.9%) Zone 2 (0.75 to 3 km radius, soil lead 100-199 µg/g) Zone 2 child BLL: • < 3.3 µg/dL (n=44, 63.2%)	• Clear distribution observed in soil samples with lead concentrations > 400 µg/g- all concentrated in area with heavy historical smelting activity. Topsoil lead concentrations decrease with distance from this area – smelting activity one of the main sources of lead. • Elevated BLL associated with increased soil Pb concentrations, particularly in areas closer to smelter sites. • Authors note that there is some possible contribution from historical soil contamination from leaded gasoline in Zone 1 and Zone 2 (close to freeways), and lead paint in housing due to age of development. • Soil cleanup ongoing in Pueblo. • 3.3 µg/dL was the lowest BLL as it represented the detection limit of the device/method used.	(Diawara et al. 2018)

Table C-3 Studies with Soil and/or BLL, Urban and Industrial Areas				
Source, location	**Sample number/depth**	**Lead concentrations**	**Notes**	**Reference**
		• 3.3 to 4.9 µg/dL (n=24, 27.6%), • >5 µg/dL (n=8, 9.1%) Zone 3 (> 3km radius), soil lead < 100 µg/g. Zone 3 child BLL • < 3.3 µg/dL (n=98, 83.7%) • 3.3 to 4.9 µg/dL (n=14, 12.0%) >5 µg/dL (n=5, 4.3%)		
Residential soil locations at varying distance from active/historical silver-lead-zinc mine, Broken Hill, Australia	3-5 samples per home, 0 to 5 cm depth BLL: 4852 children (age <5)	• Child BLL < 2 km from mine: n=782 (16%), 5.25 µg/dL (geomean). 53.71% of children in group had BLL> 5 µg/dL. • Child BLL 2-4 km from mine: n=1872 (39%), 4.49 µg/dL (geomean). 45.35% of children in group had BLL>5 µg/dL. • Child BLL > 4 km from mine: n-2198 (45%), 3.89 µg/dL (geomean). 36% of children in group had BLL>5 µg/dL.	• Every 1% increase in soil lead was associated with a 0.130% (95%CI 0.045, 0.216) increase in BLL. Soil concentration was found to be a significant predictor of blood lead. • Child BLL decreased with increasing distances from the mine (statistically significant). • Dust storm in 2009 redistributed soil in region.	(Dong et al. 2019)
Residential locations, multiple sites, France	N=484 children (ages 6-months to 6-yr) in France N=470 (interior floor dust) N=114 (interior floor dust, common areas)	• Geometric BLL in children (ages 6-months to 6-yr) determined to be 1.38 µg/dL). • 95th percentile BLL (population weighted) was 3.28 µg/dL Geometric mean, indoor dust, common areas: 32.2 µg/m2	• Household dust and tap water were determined to be the dominant exposure pathways in French children. • Specifically, tap water lead concentrations above 5 µg/L were associated with the geometric men, 75th and 90th quantiles of BLL. • Strong, statistically significant association between the use of ceramic cookware and traditional cosmetics (e.g. kohl) were observed with geometric mean BLL. • The relationship between soil lead and BLL was determined to be weak, but the authors note that the	(Etchevers et al. 2015)

Table C-3 Studies with Soil and/or BLL, Urban and Industrial Areas

Source, location	Sample number/depth	Lead concentrations	Notes	Reference
	N=472 (tap water) N=53 dust (residential exterior dust) N=315 (residential soil) N=484 (lead in paint) Samples of kohl and traditional cookware collected (if applicable)	Geometric mean, indoor dust, other: 8.7 µg/m2 Geometric mean, exterior dust: 44.4 µg/m2 Geometric mean, soil: 33.9 µg/g, median 27.2 µg/g=	impact of soil lead have indirectly been assessed through the assessment of household dust. • Cross-sectional nature of study did not include consideration of past-exposures	
Residential soils, Syracuse, New York	N=194 locations Bulk sample collected from 0-10 cm depth and composite core sample collected from 0-1 cm at each location Soil samples collected based on a 600 m x 600 m grid laid over City. Sampling focused on residential areas, avoiding building drip lines, and included a mixture of developments and parks BLL	Soil: Geometric mean 80 µg/g. 95% of samples presented concentrations in the range of 20-800 µg/g	• Over 27.6% of the children sampled (n=3375) had BLL above 10 µg/dL. • Seasonal variability in BLL evident, with increased values in the summer • Soil lead map grid results did not demonstrate a relationship with BLL. However, when data were re-screened, clear differences between age groups and races were evident. • Once soil lead data were aggregated across spatial units of sufficient scale to include at least 10 soil lead measurements each, significant statistical associations were observed.	(Johnson and Bretsch 2002)

Table C-3 Studies with Soil and/or BLL, Urban and Industrial Areas

Source, location	Sample number/depth	Lead concentrations	Notes	Reference
	N=12,228 blood samples from children ages 0-6 years, from Onondaga County Health Department			
Residential soil and water samples, Flint Michigan	N=248 (collected as part of different study, depth 3-4 inches (7.6- 10 cm) on lawns and 7 inches (18 cm) in gardens	Range of average soil concentrations: Inner city: 126-222 µg/g Within City boundary: 0 to 222 µg/g Outside boundary: 0 to 125 µg/g BLL – only percentages at or above 5 µg/dL discussed. 3.6% of children in Flint had BLL greater than 5 µg/dL before 2014, which rose to 7% in 2014 after the water source change. BLL data are for City or County, not matched with soil sampling locations.	• Detailed soil data not readily available • Areas with soil lead concentrations greater than 150 µg/g were all within City Boundaries, and generally clustered together in the inner city. These areas also overlapped with areas services by the City of Flint water network (affected by the switch in 2014). • Lead soil concentrations outside the City were lower in comparison with the in-City concentrations. City of Flint Water network does not extend to those areas. • Detailed BLL statistics not provided in article or in data source cited within	(Laidlaw et al. 2016)
Sydney estuary (Port Jackson) catchment area, Sydney Australia in 2011	N=341 soil samples (0 to 2.5 cm depth) from areas with different types of land use (residential, commercial, industrial, park, main road verge, institutions, schools, hospital) N=18 of the above collected samples submitted separately to evaluate bioaccessibility	All areas combined: mean 133 µg/g; median 61 µg/g, geomean 65 µg/g Residential areas: mean 210 µg/g; geomean 85 µg/g Open space land use: mean 71 µg/g; geomean 42 µg/g) Bioaccessible lead concentrations in urban Sydney ranged from 135 µg/g to 3727 µg/g (mean 1076 µg/g, geomean 718 µg/g). Median bioaccessibility 77%; absolute bioavailability 34%	• Highest soil lead concentrations located near major traffic throughfares. • Lowest urban lead concentrations located in northern Sydney, where traffic volumes are lower. • Exterior lead paint is noted as a significant contributor to older inner city areas. • IEUBK model used to estimate BLL from soil, assuming absolute bioavailability of 34%. Overall BLL estimated to be 2.0 µg/dL, ranging from 1.3 to 16.8 µg/dL. Approximately 8.8% of the estimated BLL were above 5 µg/dL, and 2.3% above 10 µg/dL.	(Laidlaw et al. 2017)
Residences within the Metropolitan area of	N=250 soil samples, 0-2 cm depth, majority collected by residents	Residential soil lead: 193 µg/g (mean), 110 µg/g (median), 108 µg/g (geomean), 8 -3,341 µg/g (range)	• Lead concentrations generally elevated in the central and western areas of Melbourne. • Clear spatial pattern could not be identified due to lower density of samples in some areas.	(Laidlaw et al. 2018)

Table C-3 Studies with Soil and/or BLL, Urban and Industrial Areas

Source, location	Sample number/depth	Lead concentrations	Notes	Reference
Melbourne, Australia		IEUBK model predicted BLL: 2.9 µg/dL (mean), 2.3 µg/dL (median), 2.5 µg/dL (geomean), 1.3 to 22.5 µg/dL (range)	• 20% of the samples were above the Australian guideline of 300 µg/g. • IEUBK based on a hypothetical 24-month old at each location and an assumed bioavailability of 34%. • Authors recommend future sampling to include systematic sampling (e.g. 4 samples per square kilometre)	
Soil, dust, tap water, near Superfund site (inactive mine tailings and smelter site), Dewey-Humboldt, Arizona	N = 34 composite soil samples from 34 residences with children ages 1-11 years, located within 7 miles (approx. 11 km) of site Soil sample depth not noted N= dust samples (indoors) N= 70 children for blood samples (as well as toenail and urine for arsenic)	Soil lead: Geomean: 16.9 µg/g, range: 5.39 to 59 µg/g. Dust lead (vacuumed dust): Geomean: 21.6 µg/g, range: 8.01 to 274 µg/g BLL geomean: 1.36 µg/dL, range: non-detect to 3 µg/dL	• No exceedances of lead in soil or dust were noted in the study. • All measured BLL were less than 5 µg/dL	(Loh et al. 2016)
Residential soil and dust samples, New Orleans, Louisiana	N=5,467 surface soil samples (0-2.5 cm depth) stratified by census tracts	Soil lead: 6 to > 1,600 µg/g Areas divided into high lead (> 100 µg/g) and low lead (< 100 µg/g) areas BLL data collected by the Louisiana Childhood Lead Poisoning Prevention Program before and after Hurricane Katrina in 2005 (a major weather event that altered lead deposition in the city).	• Lead-based paint in older communities as well as historical leaded fuels are known sources of impacts in the area. • Maps of soil lead were created for the entire metropolitan area • Authors suggest that the US EPA SSL of 400 µg/g is associated with a lead dust loading of approximately 16,200 µg/m^3 • Potential Lead on Play Surfaces (PLOPS) sample, allows for lead loading to be estimated. • The proportion of BLL greater or equal to 5 µg/dL was compared pre- and post Hurricane Katrina: High-lead group (pre-Katrina): 58.5% were > 5 µg/dL, Low-lead group (pre-Katrina): 24.8% > 5 µg/dL High-lead group (post-Katrina): 29.6%> 5 µg/dL. Low-lead group (post-Katrina) 7.5% > 5 µg/dL.	(Mielke et al. 2014)

Table C-3 Studies with Soil and/or BLL, Urban and Industrial Areas

Source, location	Sample number/depth	Lead concentrations	Notes	Reference
			• Conclude that reductions in soil lead and dust as a result of the deposition of non-impacted soils after the flood and the construction of new housing resulted in a substantial decline in BLL in the City, particularly the inner-city.	
Residential soil and dust samples, New Orleans, Louisiana	N= 3,238 soil samples collected before and N= 3,243 samples collected 10-years after Hurricane Katrina related floods Address geo-coded BLL data for children < 6-years of age collected by the Louisiana Childhood Lead Poisoning Prevention Program	Median soil lead: Pre-Katrina: 289 µg/g Post-Katrina: 143 µg/g Median BLL: Pre-Katrina: 5 µg/dL Post-Katrina: 1.9 µg/dL	• Highest soil lead and BLL were found in inner-city communities, and lowest soil and BLL in outer-city areas. • The deposition of low-lead soils from the coastal environment during the flood of 80% of the City during Hurricane Katrina contributed to a notable decline in child BLLs over a 10-year period. • Median soil lead concentrations decreased by a factor of 2 and median blood lead concentrations by a factor of 2.6 across all census tracts in New Orleans post-Hurricane.	(Mielke et al. 2017)
Soil samples, New Orleans, Louisiana	N=5,467 surface soil samples (0 to 2 or 3 cm depth), collected within 1 metre of busy streets or residential streets, beside houses, and in open spaces (play areas in yards or parks). City census tracts divided into high (median > 100 µg/g) and low (median < 100 µg/g) Address geo-coded BLL data for children < 6-years of age collected by the	All Sampling Areas: High Lead (> 100 µg/g), median 366 µg/g, range 2.5 to 52,798 µg/g. Low Lead (< 100 µg/g) median 44 µg/g, range 2.5 to 10,184 µg/g	• BLL above 5 µg/dL generally occur within the inner-city areas, with lower BLL in the outer-city areas. This corresponds to the differences in soil lead concentrations between these areas. • High lead areas: Pre-Katrina median BLL: 5.6 µg/dL Post-Katrina median BLL: 3.0 µg/dL • Low lead areas: Pre-Katrina median BLL: 3.0 µg/dL Post-Katrina median BLL 3.0 µg/dL • Racial and socioeconomic disparities are noted as existing between the high- and low- soil lead areas in the city. The authors hypothesize the contribution of long-term lead exposure on the health and crime rates in the City. • Hurricane Katrina related flooding resulted in the deposition of non-leaded soils, and the demolition of older housing in the inner-city.	(Mielke et al. 2013)

Table C-3 Studies with Soil and/or BLL, Urban and Industrial Areas

Source, location	Sample number/depth	Lead concentrations	Notes	Reference
	Louisiana Childhood Lead Poisoning Prevention Program			
Residential soils, Indianapolis, Indiana Study focused on Westside Cooperative Organization (WESCO) – an area with historically higher soil lead concentrations and BLL due to proximity to former point source (Avanti Superfund Site).	Soil: n=266 samples, 0-5 cm. Dust: n=7 furnace filter samples, collected over a 12-month period (Nov., Dec., Jan identified as most relevance months for this metric). BLL: data for 1999-2008 evaluated. N=12,431 Children (ages 0 – 5 years, with continuous BLL data)	Soil: WESCO community, 259 ug/g (mean), range: < 50 ug/g (min) to 1,635 ug/g (max). Interpolation by distance weighting used to estimate soil concentrations in unsampled areas of neighbourhood. Mean WESCO soil concentration impacted by three high samples collected outside non-remediated portion of Avanti Super Fund Site: 8,119, 3,759 and 2,310 ug/g. Furnace dust (Nov/Dec/Jan): Home near remediated Super Fund Site: 1,200 ug/g Other WESCO homes BLL (all children): Marion County (n=12,431), average 2.76 µg/dL, geometric mean 1.81 µg/dL. WESCO neighbourhood (N=883), average 4.28 µg/dL., geometric mean 2.9 ZIP Code 46222 (includes WESCO, n=1,664), average 3.45 µg/dL, geometric mean 2.90 µg/dL Children ages 6-30 months had significant higher average BLL than 0-5 month old children. Male BLL significantly higher than female BLL at county levels but not according to zip code.	• Spatial analysis completed over city of Indianapolis including zip-code mapping. Average concentrations for zip codes, US Census blocks were constructed. Some areas within WESCO were found to have low soil lead, with higher concentrations to the south and west. • Results suggest that resuspension of local soils is occurring (as fugitive dust), and lead concentrations are likely related to traffic volume and industrial sources. • Approximately 89% of n=5065 Homes in WESCO were built before 1960 and is fairly constant. However, age of home was not found to be a main contributor to lead due to the lack of variation in year built. • Socioeconomic and racial differences were identified as being associated with increased BLL. • For the County as a whole, urban zip codes had higher prevalence of elevated BLL in children.	(Morrison et al. 2013)

Table C-3 Studies with Soil and/or BLL, Urban and Industrial Areas				
Source, location	**Sample number/depth**	**Lead concentrations**	**Notes**	**Reference**
		Data compared to geometric mean of < 2 µg/dL for US children		
Residential areas, France	N=484 children, ages 6-months to 6-years, identified from hospital population Samples collected from households of these children Authors completed modelling to evaluate the potential impact of hypothetical intervention limits for lead in different media.	Soil (n=315), < 1 to 3,075 ug/g, geometric mean 25 ug/g Water lead: < 1 to 74 µg/L Floor dust (n=1763): <1 µg/m2 to 3204 µg/m2 Floor dust common parts of multi-residential building (n=209), 2 to 5968 µg/m2 BLL: geometric mean 1.4 µg/dL, range 0.26 to 30.8 µg/dL	• Of the children in the study, 1.1% had BLL > 5 µg/dL, and 0.13% > 10 µg/dL (French intervention level). • With exception of floor dust taken from common parts of multi-residential buildings, all concentrations (floor dust, soil, water) were significantly associated with BLLs. • Lead in floor dust, water and soils were identified as being the primary contributors to BLL. • Significant associations were also reported between BLL and age, sex, unusual exposure sources, pica, hand-to-mouth behaviours, and free health insurance. • Modelling of potential impact of various hypothetical intervention levels suggests that standards must be set low for the largest impact on the population. However, when the predicted decreases in BLL for each hypothetical limit are evaluated for confidence intervals that are statistically significant, then only reductions in tap water concentrations and interior floor dusts are relevant.	(Oulhote et al. 2013)
Soil lead concentration near primitive e-waste recycling facility, Montevideo, Uruguay	N=69 children and adolescents Soil samples collected at residences of 40 of the above individuals	Soil lead: mean 7,103 µg/g, range 650 to 19,000 µg/g BLL: First measurement: 0.3 to 28.4 µg/dL, mean 9.19 µg/dL, BLL second measurement (within 1-year), mean 5.86 µg/dL, range 0 to 19 µg/dL	• Informal recycling activities, including open cable burning to obtain copper include children and families. • Manual gathering of metals also a source of lead exposure. • Several interventions implemented after the first measurement included family education, indoor and outdoor remediation, relocation and behavioural changes.	(Pascale et al. 2016)
Soil and equipment dust, children's playground, Beijing, China	Soil samples collected at 10 cm depth from 71 different playgrounds (actual sample number not clear).	Soil lead: mean 36.2 µg/g, range 7.80 to 326 µg/g Dust lead: mean 80.5 µg/g, range 9.55 to270 µg/g Predicted child BLL as Probability of being > 5 µg/dL"	• Playgrounds from various areas of Beijing selected by grids. • Highest playground soil concentration (44.2 µg/g) collected from city centre. Lead levels lower in more rural districts. Soil lead concentrations greatest in areas with vegetation cover. • Dust lead patterns different than soil. Relatively high average concentrations across Beijing, regardless if urban	(Peng et al. 2019)

Table C-3 Studies with Soil and/or BLL, Urban and Industrial Areas				
Source, location	**Sample number/depth**	**Lead concentrations**	**Notes**	**Reference**
	N=42 Dust samples collected on playground equipment surfaces	Main city area (Soil): BLL average 0.64 µg/dL,range 0.12 to 33.6 µg/dL. Main city area (dust): BLL average 2.21 µg/dL, range 0.13 to 15.4 µg/dL Rural counties (soil): BLL average 0.27 µg/dL (range 0.16 to 0.61 µg/g) Rural counties (dust): BLL average 1.68 µg/dL, range 0.17 to 24.4 µg/dL	or rural. Higher concentrations not near roadways, railways, industry. • IEUBK and ALM models used to predict BLL	
Residential areas near former smelter site, Bunker Hill, Idaho (Retrospective of a subset of data)	Smelter closed in 1981, followed by remediation in 1986. Superfund Site. Lead Health Intervention Program (LHIP) commenced in 1988 along with a soil remediation program and household intervention program. BLL collected in late summer, and matched to dust and soil lead data. Soil from more than 3,500 properties	Subsets of records from five communities included in re-analysis: Kellogg (N=118, ages 1-9 yr), BLL (geometric mean) 6.3 µg/dL Soil (geometric mean) 435 µg/g Dust (geometric mean) 985 µg/g Page (N=15, ages 1-9 yr) BLL (geometric mean) 5.2 µg/dL Soil (geometric mean) 287 µg/g Dust (geometric mean 467 µg/g) Pinehurst (N=117, ages 1-9 yr) BLL (geometric mean) 3.7 µg/dL Soil (geometric mean) 369 µg/g Dust (geometric mean) 383 µg/g	• Authors note that bioavailability was significantly underestimated in earlier risk assessments, and that previous IEUBK modelling for the population overpredicted BLLs for over 50% of the population, likely due to assumptions around ingestion rates. • By 2002, the geometric mean BLL had decreased to 2.2 µg/dL • Study represents a retrospective re-analysis of BLL and environmental data with the intention of evaluating soil and dust ingestion rates. • The soil and dust rates between 1988 and 2002 were estimated to be 66 mg/day for children 6-months to 9-years of age, with a peak of 94 mg/day between the ages of 12 and 23-months. These ingestion rates were lower than the default IEUBK and US EPA exposure factors recommended rates for all groups (with the exception of children < 12-months of age). • Authors concluded that approximately half of the lead exposures received by children in the area were attributable to house dust and the other half to soil (including soil surrounding home environment as well as the neighbouring community).	(von Lindern et al. 2016)

Table C-3 Studies with Soil and/or BLL, Urban and Industrial Areas

Source, location	Sample number/depth	Lead concentrations	Notes	Reference
	within 21 square miles of smelter remediated with up to 1 foot of clean fill by 2002. In vitro bioaccessibility methodology for lead did not exist at the time of the original assessment	Smelterville (N=57, ages 1-9 yr) BLL (geometric mean) 6.4 µg/dL Soil (geometric mean) 242 µg/g Dust (geometric mean) 1,190 µg/g Wardner (n=5, ages 1-8 yr) BLL (geometric mean) 4.2 µg/dL Soil (geometric mean) 484 µg/g Dust (geometric mean) 959 µg/g	• The measured bioaccessibility of soil and dust lead samples were determined to be 28% and 33% respectively, which are both comparable to the IEUBK default of 30%. • Soil outside the home varied with distance from the site, and not property boundaries, and off-site exposures were as important as home exposures.	
Residential soils, New Orleans, Louisiana	Surface soil (0-2.5 cm), n=5,467 collected and stratified by 286 different census tracts within the City BLL data for n-55,551 children in 280 census tracts, 2000 to 2005	Soil: mean 249.42 µg/g, range 6.2 to 1789 µg/g Child age: mean 30.22 months, range 6 to 72 months BLL: mean 5.68 µg/dL, range 0 to 117 µg/dL	• Evaluated effect of soil lead and child age on BLL • Determined that child BLL is a curvilinear function of both age and level of exposure to neighbourhood soil lead. • Age has more of an influence at lower BLL, while soil lead has more influence at higher BLL • Concluded that a downward change in the US EPA SSL from 400 to 100 µg/g would have a significant impact on BLL and a related economic benefit	(Zahran et al. 2011)
Soil and Air, Detroit, Michigan	Atmospheric soil: derived from elemental composition of soil. Highest concentrations located inner-city Aerosol soil: measured from IMPROVE monitoring program, 2001-2009 BLL for n-367,839 children (ages 0-10 years), 2001-2009	Measured data not clearly presented in report	• Re-suspended soil was identified as a source of atmospheric lead. A 1% increase in amount of resuspended soil estimated to result in a 0.39% increased in airborne lead. • Airborne lead significantly associated with age-dependent variation in child BLL. A change of 0.0069 µg/m^3 in atmospheric lead was predicted to result in an increased in BLL in a child (1-year of age) by 10%. For a child less than 1-year of age, change of 0.0069 µg/m^3 in atmospheric lead increased the odds of a BLL > 5 µg/dL by a factor of 1.32.	(Zahran, Laidlaw, et al. 2013)

Table C-3 Studies with Soil and/or BLL, Urban and Industrial Areas

Source, location	Sample number/depth	Lead concentrations	Notes	Reference
	from tri-county areas including the City of Detroit			
Residential soils, New Orleans, Louisiana	Surface soil (0-2.5 cm), n=5,467 collected and stratified by 286 different census tracts within the City BLL data for n-55,551 children in 280 census tracts, 2000 to 2005 (same data set as Zahran et al. 2011)	1 m Busy street soils: 50th percentile 156.1 µg/g 1 m Foundation soils: 50th percentile 136.6 µg/g 1 m residential street soils: 50th percentile 104.7 µg/g Open space soils: 50th percentile, 71.1 µg/g Child age: mean 30.22 months, range 6 to 72 months BLL: mean 5.68 µg/dL, range 0 to 117 µg/dL	• Statistical analysis included consideration of soil sample location: within 1 metre of busy streets, within 1 m of residential streets within 1 m of home foundations, and open spaces (away from roads, buildings – such as large residential lots or parks). • Models used to predict BLLs by location, and to evaluate BLL according to joint conditions. • Residential street soils found to be more strongly associated with child BLL than soils near foundations, busy streets or open spaces. Residential street soil more strongly predicts variation in child BLL. •	(Zahran et al. 2013)
Multi-media exposure modelling, children 0-7 years old, US			• Probabilistic model used to evaluate child lead exposures from drinking water, soil, dust, food and air. Modelling included US EPA SHEDS-Multimedia model (Monte Carlo simulation) and the IEUBK model. • Intent of models was to determine drinking water concentrations that would keep total childhood lead exposures at 5 µg/dL or less • Determined that soil and dust are dominant exposure pathways for US children ages 0 to 2 years, followed by drinking water. The SHEDS-IEUBK model used was demonstrated to be very sensitive with respect to the soil and dust ingestion rates used for 0 -7 yr olds.	(Zartarian et al. 2017)

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APPENDIX D

Components of a Biomonitoring Study

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D-1. INTRODUCTION

This Appendix is intended to provide a description of the potential components of a biomonitoring study.

D-2. COMPONENTS OF A BIOMONITORING STUDY

The objectives of the biomonitoring study would be to:

- Measure the current level of internal exposure to lead in children (under the age of 7 years) residing in the identified at-risk areas;
- Compare levels of exposure from at-risk areas to national averages and those from less centrally located areas within the City of Winnipeg ("control areas");
- Identify personal and environmental factors (including localized exposures) associated with children's lead exposure; and,
- Identify areas of the City where additional risk management or remediation may be warranted.

The overall goal of this sampling program would be to complete a multi-neighbourhood, cross-sectional study of BLLs in children under the age of 7 years residing in the above identified areas with the intent of determining actual lead exposures that these children are receiving.

Concurrent with the collection of blood samples, environmental samples (exterior yard soil, household dust, tap water, lead paint) from within or surrounding the child's residence can be collected to examine the potential influence of lead in various media on BLLs. Household surveys completed by the child's caregivers will also be key to obtaining additional information regarding potential exposures.

A proposed approach is outlined below. The need for intervention can be determined based on the outcome of the biomonitoring and environmental sampling program. The most appropriate intervention associated with the greatest cost-benefit may require selection on a neighbourhood -to- neighbourhood or property-to-property level. Such options might include the following (or a combination of):

- On-going biomonitoring of specific individuals or areas;
- Site-specific/individual intervention to reduce child exposure. This might include re-testing and working with physicians to determine appropriate interventions;
- Additional environmental sampling;
- Implementation of dust control measures (*e.g.*, high efficiency furnace filters);
- Addition of soil covers and amendments to select locations;
- *In situ* soil remediation treatment at select locations;
- Focused soil removal/excavation;
- Education on a neighbourhood or household level.

Individual components of the study are described below.

D-2.1. Planning and Communication

As an initial component of the study, a Technical Advisory Committee (TAC) can be established to oversee the biomonitoring and environmental sampling initiatives. In addition, the formation of a Community Advisory Committee (CAC), consisting of members of the local community, will help to ensure that key considerations and concerns are heard as part of the study development process. Community leaders and organizations within these neighbourhoods should be engaged early in the project and given the opportunity to provide guidance with respect to community engagement and communications.

During the planning stage of the project, a methodology document should be compiled, outlining the activities to be completed for the project and all associated protocols (*e.g*., communications, recruitment, sample collection, shipping, analyses, statistics, surveys, consent forms, community engagement plans). This phase also would include the preparation and submission of the necessary documents and application for research ethics board (REB) approval.

A communications strategy should also be developed at an early stage and be implemented throughout the course of the study. Such a strategy should include multiple target populations including the general population, community leaders and organizations, parents/guardians of potential child participants, educational organizations (*e.g*., schools, daycares), and health care practitioners. Frequent updates to the community regarding study status and findings should be provided when possible to encourage engagement.

D-2.2. Sample Collection

Recruitment of participants would only occur once ethics approval has been received for all components of the study by all necessary parties (including the REB) and the study methodology has been finalized and approved by the Technical Advisory Committee and Community Advisory Committee.

<u>Household and Participant Selection</u>

The identification of households for participation can be based on a listing of all residences/households with children in the identified areas. This may be achieved by obtaining municipal tax data from the City. Once a list has been identified, a stratified random sampling approach can be implemented within each of the identified neighbourhoods. The sample can be stratified according to geographic area.

Each household identified from the stratified random sampling should be contacted by phone or in-person by the study team to determine whether the household contains a child eligible to participate in the study, and if so, whether the parents/guardians would be willing to have the eligible child(ren) participate. At the point of contact, a “recruitment package” can be provided and explained, and contain an overview of the study, sample consent forms, and contact information for further information about the study. If the parents/guardian agree to have their child(ren) participate, then the study team member can make arrangements for an in-house interview and sample collection. If the parents/guardian choose not to have their child(ren) participate, or through the discussions with the team member it is determined that they are ineligible to participate, a replacement household can be identified from a list generated by a random sampling exercise.

Household Visit

After consent is obtained from the parents/guardians of participating children, a household visit can be arranged. Investigators (in pairs) can then complete an in-home visit to conduct a detailed review of the informed consent process at a pre-arranged time. Once informed consent has been obtained, an interview with a parent/guardian can be completed using a structured survey instrument to collect information about the child's environment and various personal factors including household characteristics, occupations of adults residing in the home, outdoor and indoor play behaviours, diet, personal habits, etc. During the household visit, a second individual can make observations within the household for household features that may contribute to lead exposure (*e.g.* pipes, heating system, paint condition, etc.), collect samples of house dust, tap water and yard soil, and conduct lead paint analysis. Before leaving, the study team member can make an appointment for the child to visit a clinic location to provide a capillary blood sample.

Blood Sample Collection

With a blood half-life of approximately 30 days, BLLs reflect relatively recent exposure. Blood lead levels also include exposure from endogenous recirculation of lead from bone stores. Hence, elevated BLLs must be interpreted for the individual considering historical and clinical information. In advance of blood sample collection, specific protocols for sample collection, handling, storage and shipping should be defined and information collected from the selected laboratory regarding sample containers, analytical methodology and detection limits.

Blood lead studies have indicated that late summer/early fall is the most appropriate time to sample, as people tend to be outdoors more, soils are more likely to be re-suspended (due to a lack of moisture), and windows may be open. A certified phlebotomist should be on-site to collect capillary blood samples from children at designated times within a clinic setting. Capillary blood can be collected from the finger or heel of the participant, depending on the age of the participant. For infants of less than one year, the lateral or medial plantar surface of the heel is feasible; whereas, for children over one year the palmar surface of the distal segment of the middle or ring finger should be sampled.

Soil Sample Collection

For each household included in the blood lead study, samples of outdoor soil can be collected from the yard at a distance of over 1 m from the walls of buildings or painted structures. Garden soil or soils that are amended regularly should not be included in the sampling program, as they may not be representative of soil lead content. Soil sampling should consist of a composite of a minimum of 10 individual cores from a depth of approximately 2.5 cm.

Dust Sample Collection

To obtain information regarding indoor exposures, indoor dust samples can be collected from locations in each of the selected households in areas where the child(ren) who reside there spend significant amounts of time (*e.g.*, kitchen and play areas). The most recent US EPA guidance suggests that dust wipe samples be completed over areas between 1 and 2 square feet (ft^2).

Lead Paint Measurements

Commercially available lead paint test kits can be used during this household visit to evaluate the presence of lead-based paint in areas of the home that are chipping or fraying, and where children frequent.

Tap Water Sample Collection

The areas identified as having elevated soil lead concentrations and children who may be susceptible to the effects of lead may also be serviced by lead-containing plumbing components. The collection of tap water samples may include both flushed samples (*i.e.*, samples collected following a sufficient amount of time to drain the water standing within the individual home's plumbing) and first draw samples (*i.e.*, samples collected following a period of stagnation to characterize drinking water that may be influenced by residential plumbing).

D-2.3. Laboratory and Survey Result Analysis

Blood Samples

All samples should be promptly stored and shipped to the contracted laboratory according pre-defined protocols. Once received by the contracted laboratory, each sample will be analysed according to the agreed upon protocols.

Soil, Dust, Water, and Paint Samples

All samples should be handled according to pre-defined protocols and shipped to a contracted accredited laboratory that has validated test methods for lead in each type of sample media. Paint samples will be analysed for lead using a commercially available lead paint test kit on-site.

Survey Information and Data

All collected data must be handled and stored in accordance with relevant privacy legislation. All of the collected data should be entered into a database, along with data from blood and environmental samples. A separate protocol for data analysis should also be developed.

D-2.4. Results - Communication of Individual and Neighbourhood Results

Blood Lead Results

Once the laboratory analyses have been completed for the capillary blood samples, the team physician should review the results and determine the appropriate method for communicating these results to the parents/guardians. All individual results that do not require a follow-up can be provided through written notification by mail, along with general information on lead exposure and interpretation of results. For those results that require additional follow-up, a physician or medical professional should call the parents/guardians directly to discuss the results and recommended follow-up procedures. The main steps for follow-up may include:

- Venous sample re-testing ordered and arranged by the team physician – the venous sample would be analysed by the same laboratory used for the capillary samples, and would also assess haemoglobin and hematocrit levels to assist with BLL interpretation;

- Obtain permission to release capillary and venous blood test results – during the initial follow-up, the team physician would obtain permission from parents/guardians to release capillary and venous blood test results to the local Medical Officer of Health and the child's family physician;

- Work with public health officials and child's family physician - Depending on venous re-test results, the team physician would work with public health officials and the child's family physician to select and implement appropriate follow-up procedures with the family (*e.g.*, further house inspection; additional sampling of other media such as dust, soil, paint; periodic monitoring of child's blood lead levels); and,

- Obtain permission to include follow-up data in study - Permission would be sought from parents to use the data obtained from follow-up investigations for study-level reporting, ensuring confidentiality is respected and individuals and families cannot be identified through the reporting of any data.

Environmental Sampling Results

The results of the environmental sample analysis (soil, dust, paint, water) can be provided to participants by mail. This can include an interpretation of the results for their individual home based on a comparison to health-based criteria, as well as the general findings for the overall neighbourhood. Recommendations can be provided in the event that the sampling identifies levels of lead that present a potential concern.

Technical and Community Reporting

A scientific report presenting all study results should be produced, detailing methods, analyses and findings. A community-level report based on the findings of the technical report should also be produced and made available to the public. This report should be prepared for a non-technical audience, focusing primarily on the general research questions, study methods, and main findings. These results can also be presented in a brief newsletter format for the general population.

APPENDIX E

Public Notices from Agencies and Jurisdictions

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E-1. INTRODUCTION

This Appendix is intended to supplement the information provided within Task 5 of the main report. Several agencies and jurisdictions have provided recommendations to the public to reduce exposure to lead. Examples of flyers, notices and websites where information was provided for the public is presented in this Appendix. Table E- 1 includes a list of the name and website where specific information is found.

Table E- 1 Available Information for the Public based on Agency or Jurisdiction

Agency or Jurisdiction	Website or flyer name
CDC (Centers for Disease Control and Prevention)	*Lead in Soil* available at: https://www.cdc.gov/nceh/lead/prevention/sources/soil.htm
Chicago	*Protecting Chicago Children from Lead Exposure: The Checklist* Available at: https://www.chicago.gov/content/dam/city/depts/cdph/food_env/general/Lead_Poison_Prevention_Program/Safe_Kids_Lead_Checklist_7092019.pdf
Illinois Department of Public Health	*Activities to Reduce Lead Exposure* Available at: http://www.idph.state.il.us/illinoislead/ReduceLeadExposure.pdf
Iowa Department of Public Health	*Lead Poisoning How to protect Iowa Families.* Available at http://idph.iowa.gov/Portals/1/userfiles/81/protect_iowa_families_Oct2017.pdf
Massachusetts Childhood Lead Poisoning Prevention Program	*Learn about lead testing in Massachusetts and what a result means for your child*
Manitoba	*Lead Public Health – Factsheet* Available at: https://www.gov.mb.ca/health/publichealth/factsheets/lead_factsheet.pdf
Michigan Department of Health and Human Services	*Lead Poisoning Prevention—Lead and Nutrition*. Available at: https://www.michigan.gov/lead/0,5417,7-310-65222_65234---,00.html
	What you should know about nutrition and lead available at: https://www.michigan.gov/images/flintwater/What_you_should_know_about_nutrition_and_lead_524380_7.jpg
New Jersey Department of Health	*Reducing Your Exposure to Lead in Soil*. Available at: https://nj.gov/health/ceohs/documents/lead_exposure_soil.pdf.
	Safe Gardening- How to Handle Produce Grown in Contaminated Soil Lead in Soil. Available at: https://nj.gov/health/ceohs/documents/safe_gardening.pdf
New Mexico Department of Health	*New Mexico Childhood Lead Poisoning Prevention Program.* Available at: https://nmhealth.org/publication/view/help/367/
New York State Department of Health	*Get Ahead of Lead Factsheet*. Available at: https://www.health.ny.gov/environmental/lead/education_materials/fact_sheets/get_ahead/

Table E- 1 Available Information for the Public based on Agency or Jurisdiction

Agency or Jurisdiction	Website or flyer name
OSHA (Occupational Safety and Health Administration, United States Department of Labor)	*OSHA Quick Card* available at https://www.osha.gov/Publications/OSHA3680.pdf
Sacramento County News	*Lead Levels in Our Urban Environment*. Available at: https://www.saccounty.net:443/news/latest-news/Pages/Lead-Levels-in-Our-Urban-Environment-.aspx
Texas Commission on Environmental Quality	Lead testing in schools. Available at: https://www.tceq.texas.gov/drinkingwater/chemicals/lead_copper/lead-testing-in-schools-outreach-project
University of Massachusetts Center for Agriculture, Food and the Environment	*Soil Lead: Testing, Interpretation, & Recommendations.* Available at: https://ag.umass.edu/sites/ag.umass.edu/files/fact-sheets/pdf/sptnl_5_soil_lead_062316.pdf
United States Environmental Protection Agency	*Fight Lead Poisoning with a Healthy Diet- Lead poisoning prevention tips for families.* Available at: https://www.epa.gov/sites/production/files/2014-02/documents/fight_lead_poisoning_with_a_healthy_diet.pdf
	Reusing Potentially Contaminated Landscapes: Growing Gardens in Urban Soils. Available at: https://www.epa.gov/sites/production/files/2014-03/documents/urban_gardening_fina_fact_sheet.pdf
	Protect Your Family from Exposures to Lead. Retrieved September 30, 2019. Available at: https://www.epa.gov/lead/protect-your-family-exposures-lead
	Fight Lead Poisoning with a Healthy Diet. Available at: https://www.epa.gov/sites/production/files/2019-10/documents/fight_lead_poisoning_with_a_healthy_diet_2019.pdf
Washington State Department of Health	*Common Sources of Lead – Contaminated Soil*. Available at: https://www.doh.wa.gov/YouandYourFamily/HealthyHome/Contaminants/Lead/CommonSources#soil