TERMS OF REFERENCE

A HUMAN HEALTH RISK ASSESSMENT OF FLIN FLON, MANITOBA, AND CREIGHTON, SASKATCHEWAN

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1.0 INTRODUCTION

Hudson Bay Mining and Smelting (HBMS) has operated a base metal smelting complex in the city of Flin Flon, Manitoba since 1930. This facility produces copper, cadmium, and zinc metals (Henderson *et al*., 1998; Manitoba Conservation, 2007). The composition of emissions released from this complex have varied over the years as a result of variations in ore composition and improved technologies associated with the processing, recovery and smelting processes (McMartin *et al*., 1999). Generally, emissions are dominated by sulphur dioxide, zinc, iron, and lead, with smaller components of arsenic, copper, cadmium, and mercury, and trace levels of silver, aluminum, magnesium, manganese, selenium, antimony, nickel, chromium, and cobalt (McMartin *et al*., 1999). A significant reduction in the release of particulate emissions has occurred since the 1970's, beginning with the construction of a 251 m stack in 1974. Prior to this, emissions were released from a series of smaller stacks ranging from less than 30 to 69 m in height (Manitoba Conservation, 2007). The implementation of new technologies associated with the smelting process have reduced emissions by approximately 90% from pre-1974 levels (McMartin *et al*., 1999).

As a result of ongoing activities at the HBMS complex, government agencies and independent researchers have completed numerous studies focused on characterizing the content of smelter-related metals in various environmental media. Although many of these studies found that concentrations of several metals were notably elevated in media at varying distances from the smelter, it was the release of the Manitoba Conservation report in 2007 "*Concentrations of Metals and Other Elements in Surface Soils of Flin Flon, Manitoba and Creighton, Saskatchewan, 2006*" that prompted interest in the completion of a Human Health Risk Assessment (HHRA). The results of the Manitoba Conservation report indicated that concentrations of the following eleven metals were elevated relative to concentrations measured in the reference area:

- Antimony;
- Arsenic;
- Cadmium;
- Copper;
- Lead;
- Mercury;
- Molybdenum;
- Selenium;
- Silver;
- Thallium; and,
- Zinc.

Contracted by HBMS, Intrinsik Environmental Sciences Inc. (Intrinsik) was chosen to prepare the HHRA to address the potential human health risks associated with exposure to smelter-related metals in soils and other environmental media in the Flin Flon and Creighton area. As part of the initial stages of the HHRA, Intrinsik completed a "*Literature Review and Data Gap Analysis*" which involved a review of all available primary scientific literature, reports prepared and data collected by government agencies, and information provided by HBMS. Information

gathered as part of this exercise was used to determine if additional sampling and analysis is required to adequately assess exposure and risk to people in the affected areas.

This Terms of Reference (TOR) document outlines the approach for conducting a community-based HHRA of smelter-related metals in Flin Flon, Manitoba and Creighton, Saskatchewan. Section 1.1 sets out the study objectives. Section 2.0 provides a summary of background information and identifies the elements that the study will include (Study Scope). Section 3.0 describes the soil sampling program that will form the basis of the HHRA. Section 4.0 describes the approach to the HHRA process (*i.e.*, the methods).

The consultation aspects of this study are not part of the scope of this document. A Technical Advisory Committee (TAC) has been formed to provide technical guidance to HBMS and its consultants in their work to complete the HHRA and any associated studies. This TAC is comprised of representatives of HBMS, Health Canada, Saskatchewan Environment, Saskatchewan Health, Manitoba Conservation, Manitoba Health, Manitoba Water Stewardship, and Manitoba Science, Technology, Energy and Mines. In addition, a Community Advisory Committee (CAC) has been established to enable HBMS, its consultants and the various collaborating agencies to obtain input and comment from members of the public, and to demonstrate how HBMS uses that input in the decision making process.

1.1 Study Objectives

An HHRA is a scientific study, which estimates the nature and likelihood of occurrence of adverse health effects in humans following chemical exposures. For there to be a potential risk due to environmental chemical exposure, a chemical must be present, receptors (or people who may be exposed to the chemicals in question) must be present and there must be the potential for receptors to be exposed to these chemicals (*i.e.*, exposure pathways must be present such that the receptor may come in contact with the chemicals, for instance through the ingestion of soils containing the chemical). When all three factors are present (*i.e.,*chemicals, receptors and exposure pathways – see Figure 1-1), there is a potential for adverse health effects to occur if exposures to the chemicals are elevated above acceptable levels. However, the presence of all three components does not necessarily imply a risk to human health.

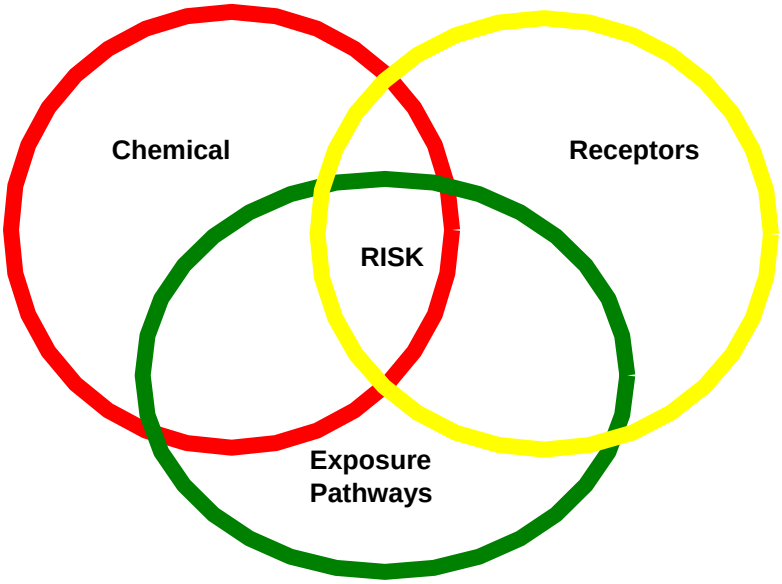

Figure 1-1 Elements Required for there to be a Potential for Risk Associated with Chemical Exposure

Based on the outcome of the Manitoba Conservation soils study, eleven metals that are associated with past or present atmospheric emissions of the HBMS complex were found at concentrations in excess of those from a selected reference location. Concentrations of seven of these metals (arsenic, cadmium, copper, lead, mercury, selenium, and thallium) were found in excess of the CCME soil quality guidelines for the protection of human health for residential/parkland soils. In addition, zinc was found in excess of the soil guideline, which is based on the protection of environmental health but does not consider human health effects. Guidelines are not provided by the CCME for three of the metals (antimony, molybdenum, and silver) found to be elevated above reference site concentrations. Although concentrations of these metals were below the CCME interim remediation criteria, the basis of these criteria are unknown and may not adequately address all relevant human health considerations.

Given that there is evidence to warrant further assessment of risks to humans as a result of the presence of certain metals in soil above CCME guidelines, and there is uncertainty regarding the potential risks associated with other metals found to be elevated in soils, the objectives of the HHRA are as follows:

Objective 1: To assess risks to human receptors residing in Flin Flon, Manitoba and Creighton, Saskatchewan as a result of exposure to metals in soil and other environmental media impacted by the activities of the HBMS complex. The HHRA will estimate the contribution from individual exposure pathways and environmental media to assist in the development of risk management objectives; and,

Objective 2: Develop risk management objectives and/or mitigation plans if unacceptable risk levels are identified in the HHRA. These risk management plans will be based on scientific approaches in consultation with the Technical Committee and the community.

The current study is considered to be a community-based risk assessment as it is evaluating a large geographical area, rather than an individual property (this would be considered a site-specific risk assessment). The advantage to this approach is that it allows the estimation of potential health risks across a broad area, and can evaluate potential exposures from a variety of input sources (*e.g.*, smelter emissions, locally grown foods, regional drinking water, *etc*.). The HHRA will be conducted according to accepted HHRA methodologies and guidance published and endorsed by such agencies as the Canadian Council of Ministers of the Environment, Environment Canada, Health Canada, and the United States Environmental Protection Agency.

2.0 BACKGROUND INFORMATION AND SCOPE OF STUDY

2.1 Background Information

The city of Flin Flon (55^{o}N, 102^{o}W) is located in west-central Manitoba on the border with Saskatchewan. It has a population of approximately 6,000. The neighbouring town of Creighton, located just southwest of Flin Flon, in Saskatchewan, has a population of approximately 1,500. Both Flin Flon and Creighton were established in the 1930's in response to demand for employment at the HBMS complex. The Flin Flon-Snow Lake greenstone belt in this area contains significant gold and base metal deposits, particularly rich in copper and zinc. Bedrock in this area is covered by discontinuous Quaternary and Holocene deposits, including till, glaciolacustrine sediments and peatlands (Henderson and McMartin, 1995). Forests are a mixed coniferous deciduous boreal community, which includes jack pine, black spruce, white spruce, balsam fir, trembling aspen, and balsam poplar (Hogan and Wotton, 1984). Wind direction is predominately towards the southeast and southwest but strong components also exist to the north-northwest and south (Environment Canada, 1990). As a result, atmospheric emissions from the HBMS complex are deposited within the Flin Flon and Creighton communities.

Emissions from the HBMS complex prior to 1974 have been estimated at 7,150 tons of particulates per year from low (30 m) stacks. A stack measuring 251 m replaced the shorter stacks in 1974 and emissions reductions brought atmospheric releases down to an estimated average of 6,834 tons per year from 1975 to 1995. The incorporation of new technologies in the 1990's reduced emissions by approximately 90% from pre-1974 levels (McMartin *et al*., 1999). The estimated distribution of contamination has varied among studies. Studies analyzing metal content in bogs and fens found elevated concentrations at distances as far as 100 km south-southeast from the smelter (Zoltai, 1988). Other studies involving the analysis of rain and snow found that the distribution of contamination was chemical specific, with distances ranging from a 33 to 217 km radius from the smelter such that Zn>Pb>As>Cu (Franzin *et al*., 1979). McMartin *et al*. (1999) found that the distance from the smelter in which concentrations returned to regional background concentrations varied for each metal but averaged 70 km for cadmium, 76 km for lead, 84 km for zinc, 85 km for mercury, 90 km for copper, and 104 km for arsenic.

Numerous studies have been conducted by government agencies and independent researchers over the past 20 years or more in which concentrations of metals in soils in the Flin Flon area have been analyzed. Results of these studies have generally been in agreement that concentrations of several metals are elevated in soils surrounding the HBMS complex. In addition, a strong positive inter-correlation has been noted by several sources indicating that these metals share a common point of origin. Similar results have been found through the analysis of snow, forest vegetation, sediments, and home garden produce, all of which generally contained increasing concentrations of smelter-related metals with increasing proximity to the smelter.

While the influence of the HBMS complex on the local environment was described in several reports, the completion of the surface soil sampling program conducted by Manitoba Conservation in August, 2006 provided further information to investigate and assess the potential risks to human health from exposure to soil and other media. This study involved the collection of soil from 93 sites in Flin Flon and 13 sites in Creighton (Manitoba Conservation, 2007) (Figure 1). In addition, to characterize areas that are believed to be minimally impacted and non-impacted, samples were collected from Bakers Narrows Provincial Park and Cranberry Portage, respectively. Samples were collected from the top 2.5 cm of soil within publicly accessible lands such as boulevards, parks, playgrounds, school yards, vacant lots and

undeveloped areas but did not focus on residential properties. The results of this study indicated that concentrations of twelve chemicals (antimony, arsenic, cadmium, copper, lead, mercury, molybdenum, selenium, silver, sulphur, thallium, and zinc) were found to be elevated relative to concentrations measured in the Cranberry Portage reference area.

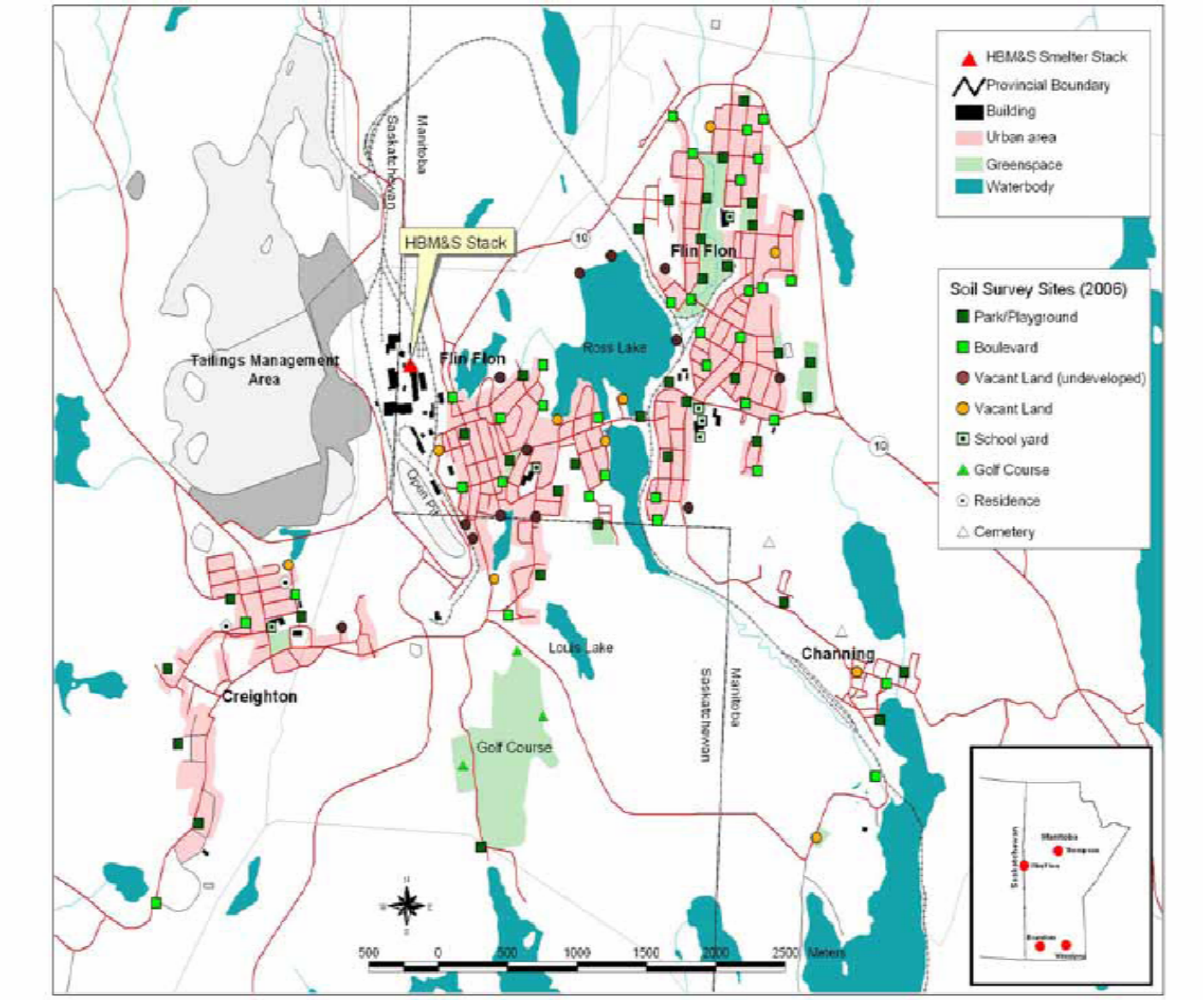

Figure 1-2 Map of Area Sampled During the Manitoba Conservation Soils Study. Bakers Narrows Provincial Park and Cranberry Portage are not Shown (Manitoba Conservation, 2007)

In addition to the surface soils study, Manitoba Conservation has conducted three additional studies in the Flin Flon area, measuring concentrations of metals in blueberries, forest soils, and home gardens, that provide valuable information for the characterization of concentrations of metals in environmental media. These studies, combined with those conducted by Saskatchewan Environment, HBMS, and those found in the primary literature, provide the basis for the Problem Formulation phase of the HHRA. Details regarding the available data

describing the metal content of various environmental media in the Flin Flon and Creighton area is provided in the *Literature Review and Data Gap Analysis* (Intrinsik, 2007).

2.2 Study Scope

This HHRA study will be a detailed, comprehensive study, which will evaluate a number of exposure pathways, chemicals and receptor groups. The specific study components are outlined here, and are discussed in greater detail in Section 4.0 of this document.

Time Scale of Risk Assessment

This study will provide an evaluation of current metal exposures, and will project estimated risk levels into the future (*i.e.*, lifetime exposures) based on current soil chemical concentrations. The HHRA will not evaluate historical impacts of, or risks related to, historical metal exposures.

Soil Sampling and Analysis

Although the Manitoba Conservation soils study has effectively characterized concentrations of metals in the soils of public areas, an HHRA will commonly assume that chronic exposure events, for children in particular, will occur at the home. Exposure to metals in soil *via* incidental ingestion and dermal contact, as well as inhalation of re-suspended dusts, is most accurately characterized using values measured from children's play areas on residential properties. In addition, children and adults spend a significant amount of time indoors, particularly within their primary residence. This is particularly true for populations living within northern environments, which are subject to long, cold winters. As a result, exposure to chemicals of potential concern (COPCs) within house dust is an important pathway to accurately assess. Although concentrations in indoor dust can be correlated to concentrations in outdoor soil and ambient air, it is preferred to use actual measured concentrations collected from various hard and soft surfaces within homes.

To address uncertainties associated with characterizing concentrations of metals in outdoor soil and indoor dust at residential locations, Intrinsik has recommended that an additional soil sampling program is completed. The collection of data from the front and backyards of residential properties as well as dust from indoor environments should be considered. As part of an additional outdoor soil and indoor dust sampling program, laboratory analysis of select samples to determine the bioaccessibility of certain metals would allow for a more accurate prediction of available exposure.

The proposed supplemental sampling program for The Flin Flon and Creighton area is outlined in Section 3.0. Further details are provided in Appendix A. Soils will be analyzed for selected metals of interest (see below). Additional soil samples from selected areas will undergo bioaccessibility testing using an *in vitro* stomach/intestinal leach protocol (see Appendix B), to determine the relative bioaccessibility of the metals of interest within soil and dust.

Selection of Chemicals of Potential Concern (COPCs)

The selection of the COPCs for the HHRA will be based on concentrations of chemicals measured in surface soil as part of the Manitoba Conservation (2007). Although soil data collected as part of additional studies completed by Manitoba Conservation which focused on forest soils, blueberries, and home garden produce will be considered, data collected during the surface soils study is considered to be the most relevant to the HHRA. Section 4.2.2 provides the screening process used in the selection of COPCs.

Selection of Receptors

In keeping with risk assessment procedures widely used in Canada and elsewhere in North America to evaluate exposures to substances in soils, a toddler will be assessed as the most highly-exposed life-stage for non-carcinogenic exposures. A composite receptor (composed of all life-stages from infant to the elderly, amortized for lifetime exposures) will be evaluated for any carcinogenic chemicals requiring assessment. The receptor characteristics to be applied in this assessment are discussed in further detail in Section 4.0 of this document.

Selection of Exposure Pathways and Supporting Rationale

This study will provide a multi-pathway assessment of potential risks. The environmental media and exposure pathways to be included in this study are as follows:

- Outdoor Soil: Direct exposure to COPCs in soil will be evaluated *via* incidental ingestion, direct dermal contact, and inhalation of particulates. The inclusion of these pathways is based on the fact that elevated levels of metals have been detected in surface soils throughout The Flin Flon and Creighton area. These pathways will be evaluated using soils data collected as part of the Manitoba Conservation soils study and any additional data collected during the recommended supplemental residential study.

- Indoor House Dust: Recent studies have indicated that indoor household dust can be an important source of metal exposures, particularly for small children who spend most of their time indoors and ingest house dust through normal repetitive hand-to-mouth activities. This is particularly true for populations living within northern environments, which are subject to long, cold winters. Ingestion of dust and soil is widely regarded as a key pathway for childhood exposure to environmental lead. As such, this pathway will be a key component of the HHRA. Many studies use exterior soil concentration data to predict indoor exposures. Although concentrations in indoor dust can be correlated to concentrations in outdoor soil and ambient air, it is preferred to use actual measured concentrations collected from various hard and soft surfaces within homes.

- Home Garden Produce: Studies conducted by HBMS (1994), Pip (1991), and Manitoba Conservation (2006) have shown that concentrations of metals in home garden produce generally increase with increasing proximity to the smelter. Concentrations of arsenic, cadmium, copper, lead, mercury, selenium, and zinc in vegetables from Flin Flon were generally higher than those from The Pas. Consistent with the Pip (1991) and HBMS (1994) studies, Manitoba Conservation (2006) found that concentrations in lettuce were typically higher than in other vegetables. Concentrations of certain metals (*e.g.*, cadmium and mercury) in vegetables were highly correlated with concentrations in soil, indicating that metals were absorbed from soil. A comparison between concentrations in washed and unwashed samples of lettuce indicated that atmospheric deposition was likely a contributing factor (Manitoba Conservation, 2006). Overall, the Manitoba Conservation study concluded that although concentrations of certain metals were elevated in vegetables grown in Flin Flon gardens, the concentrations and anticipated consumption rates are not likely to result in human health concerns for individuals consuming home garden produce (Manitoba Conservation, 2006).

Of these three primary studies, the Manitoba Conservation (2006) is anticipated to serve as the primary source of home garden produce data for the HHRA. Although data from the Pip (1991) and HBMS (1994) studies will be considered and potentially used to fill any data gaps, the data provided within the Manitoba Conservation study are more recent and robust. In addition, given that the study design and sampling program was developed to minimize the influence of several confounding factors (*e.g.*, differences in soil texture, amount of sunlight, proximity to fences or decks), the data from this study is considered to be a good representation of the effect of smelter-related emissions on concentrations of metals in home garden produce.

- Local Blueberries: The climate and landscape of the Flin Flon area promotes an abundance of wild blueberries. As a result, it is common for residents of The Flin Flon and Creighton area to pick large amounts of blueberries to be consumed over the course of the entire year. In 2000, Manitoba Conservation conducted a study in which concentrations of metals in soil and blueberries were measured from each of 13 sites at distances ranging from 1.95 km to 155 km from the smelter; 11 from the Flin Flon area, and two others likely representing regional background concentrations (Manitoba Conservation, 2000). Although soils were analyzed for numerous metals, only concentrations of lead and mercury were measured in blueberries. Concentrations of lead in washed blueberries were only found above the detection limit of 0.01 µg/g (dry weight) at two of the 13 sampling locations. Maximum concentrations of 0.3 µg/g were measured at locations 2.5 km south-southeast and 1.95 km north-northeast of the smelter. Mercury concentrations for washed berries were <0.01 µg/g (dry weight) for samples taken from all 13 locations. Although concentrations of lead and mercury in blueberries were nearly all below detection in this report, indicating that the consumption of local berries may not be a significant source of exposure, values reported by Shaw (1981) may indicate otherwise. Concentrations of lead were notably higher in this study, and concentrations of several other metals were found to be elevated at a sampling site located in close proximity to the smelter relative to the reference locations.

  To help address uncertainties, a local food survey will be distributed to residents of Flin Flon and Creighton in early 2008 to gather information on fishing, hunting, and wild berry collecting patterns. Residents will be asked to provide information on where they obtain local berries from and to indicate which family members consume local berries and an estimate the amount consumed. If the results of this survey indicate that the consumption of local berries collected from areas impacted by smelter emissions is a potentially significant source of exposure, an additional sampling program may be completed in which blueberries are analyzed for all chemicals retained as COPCs for the HHRA (see Section 4.2.2). The collection of samples may be limited to requests for donations from blueberries collected by local residents. While the spatial patterns of concentrations in blueberries throughout the area cannot be evaluated through this process, assuming that a significant number of donors will be identified, it will provide an accurate representation of the blueberries that the general population will be consuming.

- Local Fish: Given that sport-fishing during both the summer and winter months is an important recreational activity in the Flin Flon and Creighton area, consumption of local fish may be a potentially significant route of exposure to metals released by the HBMS complex. Generally, concentrations of metals in muscle tissue of fish were not consistently higher in fish sampled from Flin Flon lakes relative to fish from lakes considered to be outside of the range of smelter-related emission deposition. Concentrations of metals found in fish from the area surrounding the smelter have been

shown to be similar to concentrations observed in fish from remote lakes from the Precambrian shield of Ontario, which have not been impacted by anthropogenic sources (Harrison and Klaverkamp, 1990). However, given that there is limited recent data provided for fish from lakes that are likely to be used for recreational fishing, exposure resulting from consumption of local fish is uncertain.

As discussed for blueberries, to help address uncertainties, a local food survey will be distributed to residents of Flin Flon and Creighton in early 2008 to gather information on fishing, hunting, and wild berry collecting patterns. Residents will be asked to describe the species and sizes of fish consumed and the most common locations they are taken from. Residents will also be asked to indicate which family members consume local fish and the number of meals consumed per week for different seasons throughout the year. If this survey indicates that consumption of fish caught in Lakes that are impacted by smelter emissions is a potentially significant source of exposure, an additional fish sampling program may be completed in which the edible muscle tissues are analyzed for all chemicals retained as COPCs for the HHRA (see Section 4.2.2). As discussed for blueberries, this sampling program may rely largely on donations from local residents. This will provide a good representation of concentrations in the species and ages of fish that are typically consumed as a product of recreational fishing. Given that fishing occurs throughout the year, samples can be collected at any time.

- Drinking Water: The consumption of drinking water is a potentially important contributing source to total daily metals exposure, particularly when municipal water is taken from local lakes, which may be influenced by atmospheric deposition of smelter emissions. Drinking water for residents of Flin Flon and Creighton is provided through separate municipal resources. Drinking water for Flin Flon is taken from Cliff Lake, which is actively supplied water from Trout Lake. Drinking water for Creighton is taken from Douglas Lake. Provided as part of a Manitoba Conservation sampling program, concentrations of antimony, arsenic, cadmium, copper, lead, molybdenum, selenium, silver, thallium, and zinc have been relatively consistent from 2002 to 2006 with the exception of copper, which varies from 21 to 69 µg/L, and lead, which varies from 0.3 to 3.2 µg/L. Concentrations of molybdenum, selenium, silver, and thallium have always been below laboratory detection. Data provided by Saskatchewan Environment indicate that similar concentrations are found in drinking water supplied to the residents of Creighton.

  For Flin Flon, concentrations of mercury in drinking water are not available for any sampling period. Currently, a single sample of drinking water for the years 2005 and 2006 has been provided for the town of Creighton's Distribution System for seven of the priority metals (arsenic, cadmium, copper, lead, mercury, selenium, and zinc) (Saskatchewan Environment, 2006). No data are available for antimony, molybdenum, silver or thallium. Based on discussions with HBMS, they will arrange to sample water from a residential location in Flin Flon and a residential location in Creighton and provide a weekly analysis of the content of all COPCs to be evaluated in the HHRA. In addition, it is anticipated that a single-day large sampling event will occur in which multiple residential locations in Flin Flon and Creighton will be sampled along with the distribution centres to determine if there are any significant differences among these locations, which may need to be addressed in the HHRA.

- Ambient Outdoor Air: Atmospheric releases of emissions from the HBMS smelter as well as wind-blown dust from tailings impoundments create the potential for significant exposure to COPCs through the inhalation of ambient air. HBMS currently operates air sampling stations at Ruth Betts School in Flin Flon and at Creighton School in Creighton. HBMS reports data for TSP, PM_{10}, and $PM_{2.5}$ and metals associated with each of these fractions on a regular basis. Manitoba Conservation operates a monitor on the Provincial building and analyzes for TSP and metals associated with TSP. Since the metals associated with the PM_{10} component of outdoor air is most relevant to the HHRA for the inhalation pathway, it is anticipated that for the Provincial building data, regression equations will be used to estimate concentrations of COPCs within the PM_{10} component based on measured TSP data. Given the location of this sampling station, this data will be useful for predicting inhalation exposure to residents living within the western community of Flin Flon. The HBMS-operated samplers at Ruth Betts and Creighton School will likely provide the most useful data for other communities within the study area. Based on annual average concentrations of arsenic, cadmium, copper, lead, and zinc from 2002 to 2006, concentrations have generally declined or remained constant over this period.

  To address data gaps in concentrations of COPCs in the PM_{10} component of ambient air, HBMS has expanded the list of chemicals to be analyzed at the Ruth Betts and Creighton School locations to include all potential COPCs to be evaluated in the HHRA.

- Indoor Air: Since receptors spend a significant amount of time within their homes, the inhalation of airborne particulates in indoor air is an important exposure pathway to assess. Concentrations of COPCs associated with airborne particulates in indoor air may be a factor of concentrations in ambient outdoor air, outdoor soil, indoor dust, as well as household items and furnishings. Since measurements of COPC concentrations in indoor air are not available, a methodology for estimating these concentrations must be developed. Within the IEUBK model (Integrated Exposure, Uptake, and Biokinetic model), the U.S. EPA assumes that the concentration of lead in indoor air is 30% of the concentration measured in outdoor air. Since the origin of this assumption is not well documented, the applicability of this value to predict indoor air concentrations of other COPCs has not been established. As a result, use of alternate values to relate indoor air concentrations to measurements in outdoor air may be considered in the HHRA. Alternatively, concentrations in indoor air may be predicted using concentrations measured as part of the indoor dust survey and literature-based measurements of total PM_{10} found in residential buildings.

- Surface Water: Receptors may be exposed to COPCs in surface water as a result of direct contact during recreational activities such as swimming. Concentrations of metals in surface water in the Flin Flon area have been reported in three main studies, all of which focused primarily on Ross Lake and Flin Flon Creek as a result of the direct discharge of effluent overflow from the HBMS facility. Surface water chemistry is also available for areas that are considered to be representative of areas that may be impacted by smelter emissions but not by effluent discharge. These include Phantom Lake, Beaver Dam Creek, and Flin Flon Creek upstream of the North Weir and the Trout Lake Mine discharge (Stantec, 2005).

  Although the HHRA will consider potential exposure as a result of direct contact with surface water during recreational activities, it is not anticipated that many members of the community will be involved in recreational activities that would result in chronic

exposure to surface water in Ross Lake or Flin Flon Creek. As a result, although concentrations of metals measured these areas could be used to represent a worst-case scenario for dermal exposure to metals in surface water, concentrations measured in the reference areas are likely a more accurate representation of a chronic exposure scenario. Given that, dermal uptake of metals from surface water is not anticipated to be high exposure predicted through this pathway may not be significant relative to soil-related pathways.

- Other Foods: A key consideration in the HHRA will be that people are routinely exposed to metals in their diet, since diet is by far the greatest background source of human exposure for all inorganic elements. Information on background dietary contribution to total metals exposure is available in such sources as CEPA Priority Substance List reports, ATSDR toxicological profiles, World Health Organization Environmental Health Criteria monographs, Total Diet Study (TDS) Programs conducted by Health Canada and the U.S. FDA, and the primary scientific literature. For this HHRA, these sources will be reviewed, and relevant data on the dietary concentrations of the COPCs will be compiled and incorporated into the exposure assessment step of the HHRA. Data from the Canadian TDS, which has been conducted by Health Canada since 1969, represents the best available Canadian data on chemical concentrations in typical dietary items in several Canadian cities. Under the TDS, all foods are analyzed in a form that they would typically be consumed in by Canadians. TDS data for metals are available for the period 1993 to 1999. Findings of the TDS for selected inorganics have been previously published in Dabeka and McKenzie (1992; 1995), Dabeka *et al*. (1987; 1993), and Conacher and Mes (1993). Summarized data from these studies, as well as unpublished TDS data is available on Health Canada's Food Program Total Diet Study web pages (http://www.hc-sc.gc.ca/food-aliment/cs-ipc/fr-ra/e_tds.html). A report is available from this website (Health Canada, 2005a,b) that presents the concentrations of elements in all Health Canada TDS composite food groups. The U.S. FDA (2004a,b) has been conducting a similar TDS in the United States since 1961, and this data source will also be reviewed and considered for use in the risk assessment. The most appropriate of these information sources will be used to characterize background exposures to the metals of interest, *via* the diet.

Additional Studies

Once the HHRA is complete, the conclusions will be evaluated in order to determine whether any recommendations are required. If the results indicate that unacceptable risks may occur based on the assumptions used in the HHRA, additional studies will be considered. These studies would be limited to the specific pathways driving the risk estimates that are directly related to HBMS emissions, and would likely be limited to the following:

- Better characterization of metals in environmental media; and,
- Confirming exposure estimates by conducting biomonitoring of residents in selected areas.

If the results of the HHRA indicate that no unacceptable risks related to HBMS emissions are predicted, then no further risk assessment work will be recommended.

2.3 Elements Considered to be Outside the Study Scope

There are several elements, which are considered to be outside the scope of the HHRA, as follows:

Ecological Risk Assessment

The scope of this study will not include an ecological risk assessment, but rather, will solely focus on human health.

Consumption of Groundwater

The drinking water sources for Flin Flon and Creighton are surface water bodies. Therefore, it is our understanding that groundwater in this area is not used for potable uses such as showering or drinking. In addition, the metals of interest in this study are not volatile, and cannot infiltrate from groundwater into buildings or overlying soils. Therefore, since there is no human exposure pathway to metals in groundwater in this area, groundwater does not require further evaluation as a potential exposure pathway.

Consumption of Local Wild Game

Based on initial communications with HBMS, it is not anticipated that a significant amount of hunting will occur within the area immediately surrounding Flin Flon and Creighton. Wild game are most likely taken from areas outside the area most significantly influenced by the HBMS complex. As a result, the consumption of wild game is not expected to significantly contribute overall exposure to COPCs. This will be confirmed with a local food survey that will be distributed to residents of Flin Flon and Creighton in early 2008 to gather information on fishing, hunting, and wild berry collecting patterns.

3.0 SOIL SAMPLING PROGRAM

The characterization of chemicals in soils in the Flin Flon and Creighton area will be the result of a phased soil study. Phase 1 has already been completed by Manitoba Conservation in which surface soils were analyzed from sites in Flin Flon and Creighton. Although this study sampled surface soils from a number of publicly accessible properties, it did not focus on the surface soils of residential properties. As a result, Intrinsik recommends that a Phase 2 sampling program is conducted in which samples are taken from the surface soils in the front and backyards of residential properties of Flin Flon and Creighton. In addition, to address risks associated with exposure to chemicals in indoor dust, it is recommended that the Phase 2 program include the sampling and analysis of dust samples from homes and schools. As a component of this phase, it is also recommended that selected soil and dust samples are submitted for laboratory analysis of the bioaccessibility of COPCs.

A brief summary of the Phase 1 sampling program (*i.e.*, the Manitoba Conservation surface soils study) is provided in Section 3.1. Recommendations for the Phase 2 sampling program are provided in Section 3.2.

3.1 Phase 1 Sampling Program

The outcome of the Phase 1 soils sampling program was the identification of metals in surface soil that are in excess of concentrations representative of regional background levels and health-based soil guidelines. Concentrations of chemicals were compared to levels measured in a reference area (Cranberry Portage) as well as to the CCME soil quality guidelines protective of human health under a residential/parkland property use. Based on these comparisons, Manitoba Conservation (2007) made recommendations for which chemicals may require further assessment within an HHRA.

Manitoba Conservation found that arsenic, cadmium, copper, lead, mercury, selenium, and thallium were found at concentrations in excess of those representative of regional background concentrations, as well as the CCME soil quality guidelines protective of human health. Zinc was considered to be elevated relative to background concentrations, and although it exceeded the CCME soil quality guideline, this value does not contain a human health component. As a result, it is unknown if concentrations in Flin Flon and Creighton have the potential to cause adverse effects to human receptors. In addition, concentrations of antimony, molybdenum, silver, and sulphur were also elevated relative to background concentrations, but do not have CCME soil quality guidelines. Manitoba Conservation (2007) compared concentrations of these chemicals to CCME interim remediation criteria and found that these criteria were not exceeded.

Overall, Manitoba Conservation (2007) concluded that arsenic, cadmium, copper, lead, mercury and selenium were present at concentrations high enough to create potential risks to human health. As a result, it was recommended that these chemicals be further evaluated in an HHRA. Given that the CCME soil quality guideline for zinc does not contain a human health component value, and the basis of the interim remediation criteria for other compounds is unknown, Intrinsik will compare measured concentrations to criteria established by other jurisdictions to be protective of human health as part of the selection of COPCs in Section 4.2.2.

3.2 Phase 2 Sampling Program

The Phase 2 sampling program will include sampling of surface soils from residential properties, sampling of indoor dust from homes and schools, and the analysis of selected soil and dust samples for bioaccessibility. Recommendations for the soil and dust sampling programs are provided in Sections 3.2.1 and 3.2.2, respectively, as well as in Appendix A.

3.2.1 Soil Sampling Program

The soil sampling program would be carried out using standard soil sampling protocols and techniques and will provide a summary view of metals in residential yards in Flin Flon, Manitoba and Creighton, Saskatchewan. Previous sample locations and results provided in the "*Concentrations of Metals and Other Elements in Surface Soils of Flin Flon, Manitoba and Creighton, Saskatchewan, 2007*" will be considered in the selection of sampling locations. In total, it is recommended that 200 residential homes be sampled, with collection of soil samples from front and backyards. It is anticipated that 350 lawn (200 front yard / 150 backyard) and 50 garden soil samples will be submitted for laboratory analysis. In the event that there are not 50 gardens at the 200 homes, then these samples will be replaced by backyard samples. Given the importance of data reliance for a HHRA 5% field duplicate samples (20 samples) will also be submitted to the laboratory for analysis, for a total of 420 samples.

At each sample location (*e.g*. front yard) five core samples will be collected from 0 to 5 cm soil horizon. It is recommended that the grass thatch organic layer be removed and that the 0 to 5 cm sample be collected from the first soil horizon. The five core samples will then be composited into one sample for laboratory analysis. This composite sampling strategy will ensure that a representative concentration of each metal is collected from the area. Soil sampling collection and analysis will be consistent with Government of Manitoba and Saskatchewan requirements.

3.2.2 Indoor Dust Sampling Program

Ultimately, airborne particulates inside homes tend to settle out and become part of the settled dust that is found on furniture and floors/carpets leading to potential exposure pathways *via* dermal contact and ingestion. Sampling will involve collections from both soft and hard surfaces as described below.

Fabric Surfaces

Dust samples within the houses may be collected (depending on presence in house) from carpeted floor areas at:

- The centre of the most frequently used play area for children under the age of six;
- The main entrance used for access and egress from the house;
- The secondary, less heavily used entrance to the house;
- The main hallway of the house and evident route of high traffic flow; and from two items of upholstered furniture such as:
    - A regularly used chesterfield; and,
    - An easy chair.

Up to five samples will be recovered from fabric surfaces in each residence. Every attempt will be made to recover the same number of samples from each residence. Where variations exist (*i.e*., no carpet) additional samples will be recovered from other surfaces deemed similar at the time of sampling. If there are no carpets, area rugs are to be sampled. If insufficient number of surfaces exist for soft surface samples, additional hard surface samples will be collected. Samples will be collected where the most sensitive receptor spends the largest portion of their active time.

Hard Surfaces

Dust samples within the houses will be collected from hard surfaced areas including a commonly contacted portion of:

- The kitchen tiled floor; and,
- The sill of a window commonly accessed and most likely to be contacted by a child (likely to be in the main living area).

A total of two samples (one from a window sill and one from a tiled floor) will be recovered from hard surfaces in each residence. Every attempt will be made to recover the same number of samples from each residence. Samples will be collected in the main living area where the most sensitive receptor is likely to spend the largest portion of their active time.

Tenant Questionnaire

The occupants will be asked to keep a diary of time spent and activities undertaken in the house during the sampling period. A questionnaire will be administered to the occupants by outlining number of people and their ages in the home; activities/hobbies undertaken in the home *etc*. The field technician will also fill out a questionnaire summarizing the observed actions of dust levels and activities/hobbies in the house.

Lead-in-paint Sampling

Based on the historical use of lead in paints and the age of the community, samples of paint will be taken from the interior of the homes selected for the indoor dust assessment. The data from the lead paint assessment will be combined with the indoor dust sampling results for use in the HHRA.

4.0 HUMAN HEALTH RISK ASSESSMENT METHODS

HHRA procedures are based on the fundamental dose-response principle of toxicology, “the dose makes the poison”. That is, the response of an individual to a chemical exposure increases with increasing chemical concentration in critical target tissues where adverse effects may occur. The concentrations of chemicals in the target tissues (the delivered dose) are determined by the degree of exposure, which is related to the chemical concentrations in the environment where the receptor resides or visits.

The HHRA for the town of Flin Flon, Manitoba and Creighton, Saskatchewan, will be conducted according to widely accepted HHRA methodologies and guidance published and endorsed by such agencies as the Health Canada Guidance on Human Health Preliminary Quantitative Risk Assessment (Health Canada, 2004), and the United States Environmental Protection Agency Risk Assessment Guidance for Superfund (U.S. EPA, 1989) in addition to various HHRA guidance updates published by U.S. EPA from the early 1990s to the present.

A HHRA is different from a community health study. Community health studies may involve such elements as questionnaires, interviews, medical record reviews and collection of biological tissue or fluid samples (*e.g.*, blood, urine, hair) to directly measure human exposures. While these types of information, in some situations, can be valuable supplementary information for a HHRA, they are not components of the established HHRA framework that is described below.

The following sections describe the human health risk assessment framework and methodology proposed for the HHRA for the current study.

4.1 The Human Health Risk Assessment Framework

The HHRA framework to be applied at this site will follow the standard HHRA framework that is composed of the following steps:

i) Problem formulation;
ii) Exposure assessment;
iii) Hazard assessment; and,
iv) Risk characterization.

The terminology within this framework follows that laid out by Health Canada (2004) for Guidance on Human Health Screening Level Risk Assessment (SLRA). It must be recognized that the proposed approach to this study is beyond this guidance (*i.e.*, the current study is a more complex Site-Specific Risk Assessment than a SLRA), but federal guidance for these types of assessments is still under development (Health Canada, 2004). Figure 4-1 outlines the HHRA paradigm, as per Health Canada and U.S. EPA.

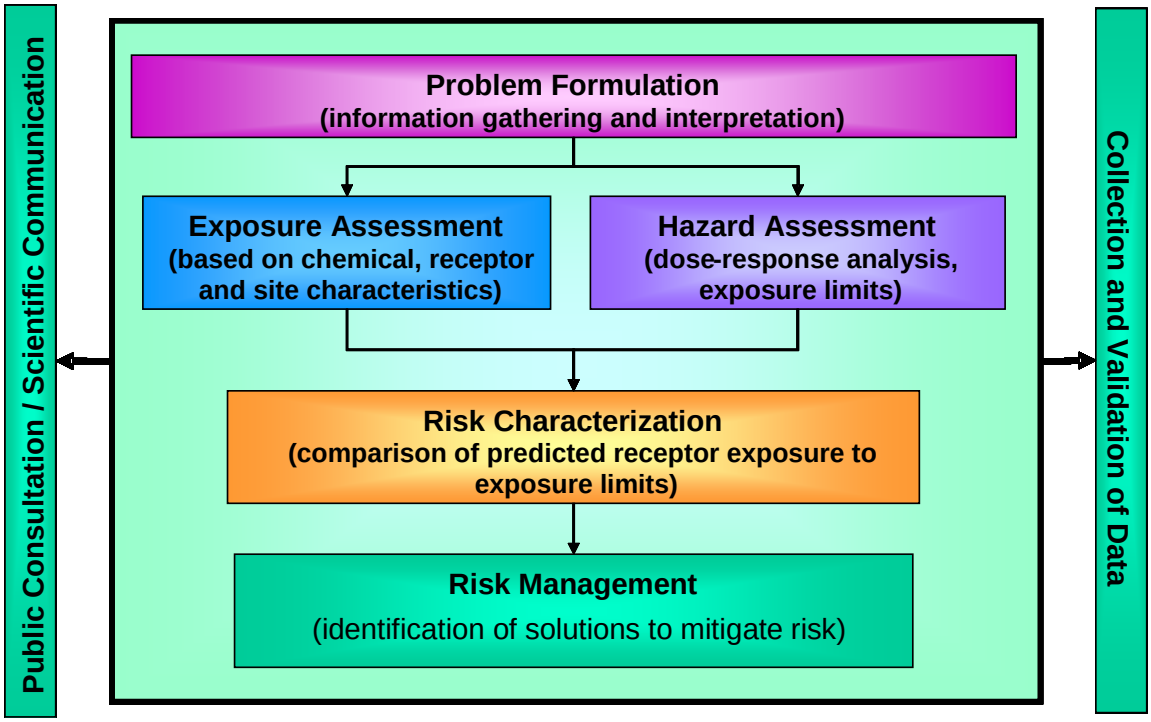

Figure 4-1 Overview of the Risk Assessment Framework

Risk assessment is an iterative process. In some instances, screening level risk assessments (SLRA) are first conducted; however, these types of SLRA are typically associated with larger levels of uncertainty (relative to more detailed assessments) due to the lack of site-specific information. As a result, it is necessary for SLRA to rely on a larger number of conservative assumptions to compensate for the lack of site-specific data. It is not uncommon for SLRA to conclude that specific areas of the assessment are associated with a large degree of uncertainty and often recommend that additional data collection and analysis be preformed. Hence, a SLRA can often result in recommendations for further data collection and the subsequent completion of a more detailed HHRA.

With this in mind, the comprehensive community-based HHRA should be conducted using the most appropriate and up-to-date site-specific data and information available at the time. Intrinsk has already conducted a 'Literature Review and Data Gap Analysis' (Intrinsik, 2007) that provided recommendations concerning the need to collect additional site-specific data in support of a detailed community-based HHRA.

As previously indicated, one of the primary objectives of the HHRA is to characterize the potential human health risks of individuals living in the towns of Flin Flon and Creighton as result of exposures to elevated levels of metals found in various local environmental media. The HHRA will also need to develop property-specific soil standards (PSSSs). A PSSS is derived using all of the assumptions, data and input parameters that were used to develop the human health risk estimates. A PSSS is typically defined as the average chemical concentration in soil within a given exposure unit (EU) or area that corresponds to an acceptable level of risk (U.S. EPA, 2001). In other words, the PSSS is the concentration in soil within a given area (*e.g.*, the town of Flin Flon, Creighton, an individual residential lot, *etc*.) which would yield an acceptable level of risk.

4.2 Problem Formulation Stage

This first step in the HHRA process is an information gathering and interpretation stage that plans and focuses the study on critical areas of concern for the site or area being evaluated. Problem Formulation defines the nature and scope of the work to be conducted, permits practical boundaries to be placed on the overall scope of work and ensures that the assessment is directed at the key areas and issues of concern. This step is critical to the success of the risk assessment as sound planning during the problem formulation step reduces the need for significant modifications once the risk assessment has begun. The data gathered and evaluated in this step provide information into the physical layout and characteristics of the Study Area, possible exposure pathways, potential human receptors, COPCs, and any other specific areas or issues of concern to be addressed.

The key tasks requiring evaluation within the problem formulation step include the following:

- *Site Characterization* – delineation of study area, and review of available site data to identify factors affecting the availability of contaminants to potential receptors, such as location and medium of contamination;

- *Identification of Chemicals of Potential Concern (COPCs)* - identification of the chemicals of potential concern based on site environmental monitoring data;

- *Receptor Characterization* - identification of "receptors of concern", which in this study include those persons with the greatest probability of exposure to chemicals from the site and those that have the greatest sensitivity to these chemicals; and,

- *Identification of Exposure Pathways* – consideration of various factors that influence the means by which receptors come into contact with COPCs in environmental media including: chemical-specific parameters, such as solubility and volatility; characteristics of the site, such as physical geography, geology, and hydrogeology; as well as the physiology and behaviour patterns of receptors.

The outcome of these tasks forms the exposure scenarios which are the basis of the approach taken in the risk assessment, defines the scope of the HHRA, and ensures concerns of all stakeholders are adequately addressed. Stakeholder consultation can be a critical component of the problem formulation step in ensuring that concerns of all stakeholders are identified from the outset.

The approach to be taken in each of these aspects of the Problem Formulation stage is outlined below.

4.2.1 Site Characterization

Site characterization typically includes the following activities:

- Establishment of the spatial and temporal boundaries;
- Site visit(s) and reconnaissance;
- Review of past site reports/investigations;
- Interviews with persons knowledgeable about the site;
- Description of the physical characteristics of the site (*e.g.*, geology, hydrogeology, and general topography);

- Consideration of historical and potential future land uses; and,
- An overview of site regulatory status (*e.g.*, classifications of site by regulatory agencies, description of agreements, compliance issues, *etc*.), if applicable.

In the case of the current HHRA, a detailed Literature Review and Data Gap Analysis was completed by Intrinsik (Intrinsik, 2007) to determine if additional sampling and analysis is required to adequately assess exposure and risk of individuals in the Flin Flon and Creighton areas. The Intrinsik (2007) Report provides a number of recommendations with respect to the collection and analysis of additional site-specific environmental media.

The information generated through the remaining tasks has been considered in the development of this study design and these remaining tasks will be undertaken in greater detail by the consultant, and will be documented in detail in the HHRA.

4.2.2 Identification of Chemicals of Potential Concern

It is common practice in HHRAs to limit the number of chemicals evaluated to those chemicals that, due to their environmental concentrations, distribution, or chemical and toxicological properties, have the greatest potential to contribute to health risks to individuals residing in the study area. However, it is important to note that the identification of a substance as a COPC does not automatically lead to the conclusion that the substance is, in fact, a contributor to health risk. Rather, the appropriate conclusion is that those substances identified as COPCs should be the subject of further evaluation. This is done because it is impractical in terms of time and cost to conduct a risk assessment for every chemical that has been found to occur in a particular area. In addition, the concentrations of many chemicals associated with a particular area may be similar to chemical concentrations found naturally in the area, rather than as a result of current or former human activities. It is also preferable to comprehensively evaluate a smaller number of chemicals, which represent the greatest concern to people living in the area under consideration, than it is to conduct a less detailed risk assessment on a larger number of chemicals.

4.2.2.1 Chemical Screening

The selection of the COPCs should be a multifaceted approach involving the use of background soil concentrations and human health-based soil quality criteria developed by recognized regulatory authorities (*e.g.,* CCME, Ontario MOE, U.S. EPA Region IX, *etc.*). Other factors, including the frequency of COPC detection and the consideration of the chemical composition of facility air emissions should also be utilized during the screening process.

For the purposes of the current TOR, a preliminary screening against human health-based soil quality criteria recommended for use by recognized regulatory agencies has been completed. It is recommended that a hierarchy of human health-based soil quality guidelines be used. When available, it is recommended that the Canadian Council of Ministers of the Environment (CCME, 2002) Soil Quality Guidelines (SQG) for the protection of human health (under a residential scenario) be used. For COPCs lacking a CCME SQG, the human health component value to the Ontario Ministry of the Environment (MOE) Soil Standards (MOE, 2005) should be applied. For those remaining COPCs lacking both a MOE component value and a CCME health-based SQG, the U.S. EPA Region IX preliminary remediation goals (PRG) can be applied. The U.S. EPA Region IX PRGs are environmental media concentrations that are considered protective of human health during prolonged exposure over a lifetime. These values have been divided by a factor of five to reflect the CCME's preferred approach to only allow exposure from a single

environmental medium to account for 20% of the toxicological reference value. Table 4-1 provides a cursory comparison between the maximum observed soil concentration reported by Manitoba Conservation (2007) and human health-based soil quality criteria.

Table 4-1 Chemical Screening

Metal	*Maximum Soil Concentration (µg/g)*[1]	*CCME Human Health SQG (µg/g)*[2]	*Ontario MOE Soil Standard - Human Health Component Value (µg/g)*[3]	*U.S. EPA Region IX Residential PRG (µg/g)*[4]
Aluminum	36,600	-		15,200
Antimony	11.2	-	13	
Arsenic	454	12		
Barium	239	-	3,700	
Beryllium	3.0	-	0.37	
Boron	62.0	-		3,200
Cadmium	88.5	14		
Calcium[5]	41,800			
Chromium	245	220		
Cobalt	45.0	-	2,700	
Copper	5,620	1100		
Iron	77,600	-		4,600
Lead	1,990	140		
Magnesium[5]	28,900			
Manganese	996	-		360
Mercury	898	6.6		
Molybdenum	8.0	-	170	
Nickel	93.0	-	310	
Phosphorous[5]	5,670			
Potassium[5]	8,750			
Selenium	260	28		
Silver	7.5	-	98	
Sodium[5]	1,440			
Strontium	157	-		9,400
Thallium	2.7	1.0		
Tin	77.0	-		9,400
Titanium	1,650	-		20,000
Vanadium	85.0	-	470	
Zinc	16,500	-	16,000	
Zirconium	18.0	-		

1 Maximum measured soil concentration from the Flin Flon and Creighton Soil Survey (Manitoba Conservation, 2007).

2 Soil Quality Guideline (SQG) in soil protective of direct human contact recommended for use by the Canadian Council of Ministers of the Environment (CCME) (CCME, 2002).

3 Human Health Component Value for Use in the derivation of Soil Standards put forward by the Ontario Ministry of the Environment (O. Reg. 153/04).

4 United States Environmental Protection Agency (Region 9) Preliminary Remediation Goals (PRGs) for residential property use divided by a factor of five (US. EPA Region IX, 2004).

5 These elements are considered essential nutrients and, therefore, may not screen into the HHRA.

As previously indicated, a multifaceted approach involving the use of background soil concentrations, human health-based soil quality criteria, frequency of COPC detection, and the consideration of the chemical composition of facility air emissions should be utilized during the screening process. Maximum concentrations of COPCs that exceed the health-based soil criteria should also be compared against a regional background dataset. Secondly, the

frequency of exceedance should also be examined. For example, although Table 4-1 indicates that the maximum chromium concentration in soil of 245 µg/g exceeds the health-based soil criteria of 220 µg/g, an examination of the dataset indicates that of approximately 330 samples, only one sample exceeded 220 µg/g.

4.2.3 Receptor Identification and Characterization

A human receptor is a hypothetical person (*i.e.,* an infant, toddler, child, adolescent, or adult) who may reside, spend leisure time and/or work in the area being investigated and is, or could potentially be, exposed to the chemicals identified as being of COPCs. General physical and behavioural characteristics specific to the receptor type (*e.g.*, body weight, breathing rate, food consumption rate, *etc*.) are used to approximate the amount of chemical exposure received by each receptor. The HHRA must be sufficiently comprehensive to ensure that those receptors with the greatest potential for exposure to COPCs, and those that have the greatest sensitivity, or potential for developing adverse effects from these exposures, are included. With this in mind, the selection of hypothetical, reasonable "worst-case" receptors, with somewhat exaggerated life style habits (to ensure a conservative assessment), should be developed for consideration in the HHRA. Due to differences in physiological characteristics and activity patterns between children and adults, the exposures received by a child and an adult will be different. Consequently, the potential risks estimated for the same COPC will differ depending on the receptor chosen for evaluation.

For chemicals considered to be carcinogenic, it is common to assess exposure over a lifetime, as development of cancer is a long term process that may take many years to manifest itself. For this reason, a special type of receptor called a "lifetime" or "composite" receptor is selected for evaluation of potential carcinogenic risks. This receptor is a "composite" of all relevant life stages for which exposure will be evaluated. Health risks associated with exposure to carcinogenic compounds are usually expressed as an estimate of excess or incremental lifetime cancer risk (ILCR) resulting from exposures to a particular source. Thus, risks associated with carcinogenic compounds are predicted using the average daily dose over a human receptor's entire life span.

In order to allow a comprehensive assessment of carcinogenic COPCs, all five age classes will be evaluated in the study (as per Health Canada, 2004):

i. Infant (0 to 6 months);
ii. Preschool child or toddler (7 months to 4 years);
iii. Child (5 years to 11 years);
iv. Adolescent (12 to 19 years); and,
v. Adult (20 years and over).

For non-carcinogens, the toddler (typically the most sensitive receptor) should be used in estimating exposure and risk.

In order to evaluate potential exposures, it is necessary to characterize the physiological and behavioural characteristics of each receptor group. Several published sources should be considered in the selection of these parameters, including:

- Federal Contaminated Sites Risk Assessment in Canada. PART I: Guidance on Human Health Risk Preliminary Quantitative Risk Assessment (PQRA). (Health Canada, 2004);
- Procedures for the Use of Risk Assessment under Part XV.1 of the Environmental Protection Act. (MOE, 2005);
- Compendium of Canadian Human Exposure Factors for Risk Assessment. O'Connor Associates Environmental Inc. 1155-2720 Queensview Dr., Ottawa, Ontario. (Richardson, 1997);
- Health Canada, (1994) Human Health Risk Assessment for Priority Substances: Canadian Environmental Protection Act: ISBN 0-662-22126-5;
- Risk Assessment Guidance for Superfund Volume I: Human Health Evaluation Manual (Part E, Supplemental Guidance for Dermal Risk Assessment) Final. EPA/540//R/99/005. July, 2004. (U.S. EPA, 2004a);
- Short Sheet: Overview of the IEUBK Model for Lead in Children. Office of Solid Waste and Emergency Response. U.S. Environmental Protection Agency. Washington D.C. (U.S. EPA, 2004b); and,
- The U.S. EPA Human Health Risk Assessment Protocol for Hazardous Waste Combustion Facilities. (U.S. EPA, 2005).

These sources have been used in numerous HHRAs that have been critically reviewed and accepted by regulatory agencies across Canada and the United States. Both the Compendium of Canadian Human Exposure Factors for Risk Assessment (Richardson, 1997) and Health Canada (2004) rely on data from published and reliable Canadian sources, such as Health Canada, Statistics Canada, and the Canadian Fitness and Lifestyles Research Institute. Where insufficient data are available in these sources to appropriately characterize relevant activity patterns and/or behavioural/physiological characteristics of a certain receptor group, other appropriate sources such as the U.S. EPA Exposure Factors Handbook (U.S. EPA, 1997) will be used to supplement the receptor parameter dataset.

For the study, receptor characteristics reflective of the Reasonable Maximum Exposure (RME) should be selected. A preliminary list of parameters and assumptions describing the physiological and behavioural characteristics of each receptor evaluated in the HHRA is provided in the following tables (Table 4-2 to 4-7). It must be recognized that as the HHRA moves forward, some of the assumptions and data that are used may change somewhat from what is presented in these tables.

Table 4-2 Receptor Characteristics and Assumptions for the Residential Infant Receptor				
Receptor Parameter	***Description***	***Units***	***Value***	***Reference/Comment***
AT	averaging time	days	183	Health Canada (2004)
ED	exposure duration	yr	0.5	Health Canada (2004)
EF_s	exposure frequency – residential	days/yr	365	Health Canada (2004)
EF_r	exposure frequency – recreational	Days/yr	5.8	Health Canada (2006)
TSO	time spent outdoors	mins/day	90	Richardson, 1997; recommended by Health Canada (2004)
TSI	time spent indoors	mins/day	1,350	Calculated
BW	body weight	kg	8.2	Richardson, 1997; recommended by Health Canada (2004)
BR	breathing rate	m^3/day	2.1	Richardson, 1997; recommended by Health Canada (2004)
WIR	water intake rate	L/day	0.3	Richardson, 1997; recommended by Health Canada (2004)
SIR	soil intake rate	g/day	0.01	Health Canada (2004); U.S. EPA (2002)
IDIR	dust intake rate	g/day	0.01	Health Canada (2004); U.S. EPA (2002)
SAH	surface area – hands	cm^2	320	Health Canada (2004)
SAA	surface area – arms	cm^2	550	Health Canada (2004)
SAL	surface area – legs	cm^2	910	Health Canada (2004)
FORIR	breast milk intake	kg/day	0.7	U.S. EPA (2005)

Table 4-3 Receptor Characteristics and Assumptions for the Residential Toddler Receptor				
Receptor Parameter	***Description***	***Units***	***Value***	***Reference/Comment***
AT	averaging time	days	1,643	Health Canada (2004)
ED	exposure duration	yr	4.5	Health Canada (2004)
EF_s	exposure frequency –residential	days/yr	365	Health Canada (2004)
EF_r	exposure frequency - recreational	days/yr	5.8	Health Canada (2006)
EF_{swim}	swim events per year - recreational	events/yr	30	U.S. EPA, 2003; based on the 90th percentile swim events per month from U.S. EPA (1997) for 3 months per year
ED_{swim}	duration of swimming event - recreational	hours/event	2.3	U.S. EPA, 2003; recommended exposure duration for long-term exposure for children 5-11 from U.S. EPA (1997)
TSO	time spent outdoors	mins/day	90	Richardson, 1997; recommended by Health Canada (2004)
TSI	time spent indoors	mins/day	1,350	Calculated
BW	body weight	kg	16.5	Richardson, 1997; recommended by Health Canada (2004)
BR	breathing rate	m^3/day	9.3	Richardson, 1997; recommended by Health Canada (2004)
WIR	water intake rate	L/day	0.6	Richardson, 1997; recommended by Health Canada (2004)
WIR_{swim}	water ingestion while swimming	L/hrs	0.05	U.S. EPA (2004a)
SIR	soil intake rate	g/day	0.04	Health Canada (2004); U.S. EPA (2002)
IDIR	dust intake rate	g/day	0.04	Health Canada (2004); U.S. EPA (2002)
SAH	surface area – hands	cm^2	430	Health Canada (2004)
SAA	surface area – arms	cm^2	890	Health Canada (2004)
SAL	surface area – legs	cm^2	1,690	Health Canada (2004)
IR_{exp}	ingestion - aboveground exposed produce	g/kg/d dw	0.8	U.S. EPA (2005); Table C-1-2; time weighted mean
$IR_{protected}$	ingestion - aboveground protected produce	g/kg/d dw	1.5	U.S. EPA (2005); Table C-1-2; time weighted mean
IR_{below}	ingestion - belowground produce	g/kg/d dw	0.2	U.S. EPA (2005); Table C-1-2; time weighted mean

Table 4-4 Receptor Characteristics and Assumptions for the Residential Child Receptor

Receptor Parameter	*Description*	*Units*	*Value*	*Reference*
AT	averaging time	days	2,555	Health Canada (2004)
ED	exposure duration	yr	7.0	Health Canada (2004)
EF_s	exposure frequency – residential	days/yr	365	Health Canada (2004)
EF_r	exposure frequency - recreational	days/yr	5.8	Health Canada (2006)
EF_{swim}	swim events per year - recreational	events/yr	30	U.S. EPA, 2003; based on the 90th percentile swim events per month from U.S. EPA (1997) for 3 months per year
ED_{swim}	duration of swimming event - recreational	hours/event	2.3	U.S. EPA, 2003; recommended exposure duration for long-term exposure for children 5-11 from U.S. EPA (1997)
TSO	time spent outdoors	mins/day	90	Richardson, 1997; recommended by Health Canada (2004)
TSI	time spent indoors	mins/day	1,350	calculated
BW	body weight	kg	32.9	Richardson, 1997; recommended by Health Canada (2004)
BR	breathing rate	m^3/day	14.5	Richardson, 1997; recommended by Health Canada (2004)
WIR	water intake rate	L/day	0.8	Richardson, 1997; recommended by Health Canada (2004)
WIR_{swim}	water ingestion while swimming	L/hrs	0.05	U.S. EPA (2004a)
SIR	soil intake rate	g/day	0.01	Health Canada (2004); U.S. EPA (2002)
IDIR	dust intake rate	g/day	0.01	Health Canada (2004); U.S. EPA (2002)
SAH	surface area – hands	cm^2	590	Health Canada (2004)
SAA	surface area – arms	cm^2	1,480	Health Canada (2004)
SAL	surface area – legs	cm^2	3,070	Health Canada (2004)
IR_{exp}	ingestion - aboveground exposed produce	g/kg/d dw	0.8	U.S. EPA (2005); Table C-1-2; time weighted mean
$IR_{protected}$	ingestion - aboveground protected produce	g/kg/d dw	1.5	U.S. EPA (2005); Table C-1-2; time weighted mean
IR_{below}	ingestion - belowground produce	g/kg/d dw	0.2	U.S. EPA (2005); Table C-1-2; time weighted mean

Table 4-5 Receptor Characteristics and Assumptions for the Residential Teen Receptor				
Receptor Parameter	***Description***	***Units***	***Value***	***Reference/Comment***
AT	averaging time	days	2,920	Health Canada (2004)
ED	exposure duration	yr	8.0	Health Canada (2004)
EF_s	exposure frequency – residential	days/yr	365	Health Canada (2004)
EF_r	exposure frequency - recreational	days/yr	5.8	Health Canada (2006)
EF_{swim}	swim events per year - recreational	events/yr	30	U.S. EPA, 2003; based on the 90th percentile swim events per month from U.S. EPA (1997) for 3 months per year
ED_{swim}	duration of swimming event - recreational	hours/event	1.7	U.S. EPA, 2003; recommended exposure duration for long-term exposure for children 12-17 from U.S. EPA (1997)
TSO	time spent outdoors	mins/day	90	Richardson, 1997; recommended by Health Canada (2004)
TSI	time spent indoors	mins/day	1,350	Calculated
BW	body weight	kg	59.7	Richardson, 1997; recommended by Health Canada (2004)
BR	breathing rate	m^3/day	15.8	Richardson, 1997; recommended by Health Canada (2004)
WIR	water intake rate	L/day	1.0	Richardson, 1997; recommended by Health Canada (2004)
WIR_{swim}	water ingestion while swimming	L/hrs	0.05	U.S. EPA (2004a)
SIR	soil intake rate	g/day	0.01	Health Canada (2004); U.S. EPA (2002)
IDIR	dust intake rate	g/day	0.01	Health Canada (2004); U.S. EPA (2002)
SAH	surface area – hands	cm^2	800	Health Canada (2004)
SAA	surface area – arms	cm^2	2,230	Health Canada (2004)
SAL	surface area – legs	cm^2	4,970	Health Canada (2004)
IR_{exp}	ingestion - aboveground exposed produce	g/kg/d dw	0.3	U.S. EPA (2005); Table C-1-2; adult intake
$IR_{protected}$	ingestion - aboveground protected produce	g/kg/d dw	0.6	U.S. EPA (2005); Table C-1-2; adult intake
IR_{below}	ingestion - belowground produce	g/kg/d dw	0.1	U.S. EPA (2005); Table C-1-2; adult intake

Table 4-6 Receptor Characteristics and Assumptions for the Residential Adult Receptor

Receptor Parameter	*Description*	*Units*	*Value*	*Reference*
AT	averaging time	days	22,300	Health Canada (2004)
ED	exposure duration	yr	56.0	Health Canada (2004)
EF_s	Exposure frequency - residential	days/yr	365	Health Canada (2004)
EF_r	exposure frequency - recreational	days/yr	5.8	Health Canada (2006)
EF_{swim}	swim events per year - recreational	events/yr	30	U.S. EPA, 2003; based on the 90th percentile swim events per month from U.S. EPA (1997) for 3 months per year
ED_{swim}	duration of swimming event - recreational	hours/event	1.3	U.S. EPA, 2003; recommended exposure duration for long-term exposure for adults from U.S. EPA (1997)
TSO	time spent outdoors	mins/day	90	Richardson, 1997; recommended by Health Canada (2004)
TSI	time spent indoors	mins/day	1,350	Calculated
BW	body weight	kg	70.7	Richardson, 1997; recommended by Health Canada (2004)
BR	breathing rate	m^3/day	15.8	Richardson, 1997; recommended by Health Canada (2004)
WIR	water intake rate	L/day	1.5	Richardson, 1997; recommended by Health Canada (2004)
WIR_{swim}	Water ingestion while swimming	L/hrs	0.05	U.S. EPA (2004a)
SIR	soil intake rate	g/day	0.01	Health Canada (2004); U.S. EPA (2002)
IDIR	dust intake rate	g/day	0.01	Health Canada (2004); U.S. EPA (2002)
SAH	surface area – hands	cm^2	890	Health Canada (2004)
SAA	surface area – arms	cm^2	2,500	Health Canada (2004)
SAL	surface area – legs	cm^2	5,720	Health Canada (2004)
IR_{exp}	ingestion - aboveground exposed produce	g/kg/d dw	0.3	U.S. EPA (2005); Table C-1-2; adult intake
$IR_{protected}$	ingestion - aboveground protected produce	g/kg/d dw	0.6	U.S. EPA (2005); Table C-1-2; adult intake
IR_{below}	ingestion - belowground produce	g/kg/d dw	0.1	U.S. EPA (2005); Table C-1-2; adult intake

Table 4-7 Receptor Characteristics and Assumptions for the Residential Composite Receptor				
Receptor Parameter	***Description***	***Units***	***Value***	***Reference***
AT	averaging time	days	29,200	Health Canada (2004)
ED	exposure duration	yr	75.0	Health Canada (2004)
EF_s	exposure frequency – residential	days/yr	365	Health Canada (2004)
EF_r	exposure frequency - recreational	days/yr	5.8	Health Canada (2006)
EF_{swim}	swim events per year - recreational	events/yr	30	U.S. EPA, 2003; based on the 90th percentile swim events per month from U.S. EPA (1997) for 3 months per year
ED_{swim}	duration of swimming event - recreational	hours/event	1.5	U.S. EPA, 2003; composite of all age classes
TSO	time spent outdoors	mins/day	90	Richardson, 1997; recommended by Health Canada (2004)
TSI	time spent indoors	mins/day	1,350	calculated
BW	body weight	kg	63.3	Health Canada (2004); Composite of all age classes
BR	breathing rate	m^3/day	15.4	Health Canada (2004); Composite of all age classes
WIR	water intake rate	L/day	1.3	Health Canada (2004); Composite of all age classes
WIR_{swim}	water ingestion while swimming	L/hrs	0.05	U.S. EPA (2004a)
SIR	soil intake rate	g/day	0.01	Health Canada (2004); Composite of all age classes
IDIR	dust intake rate	g/day	0.01	Health Canada (2004); Composite of all age classes
SAH	surface area – hands	cm^2	833	Health Canada (2004); Composite of all age classes
SAA	surface area – arms	cm^2	2,300	Health Canada (2004); Composite of all age classes
SAL	surface area – legs	cm^2	5,195	Health Canada (2004); Composite of all age classes
IR_{exp}	ingestion - aboveground exposed produce	g/kg/d dw	0.4	U.S. EPA (2005); Table C-1-2; composite of all ages
$IR_{protected}$	ingestion - aboveground protected produce	g/kg/d dw	0.8	U.S. EPA (2005); Table C-1-2; composite of all ages
IR_{below}	ingestion - belowground produce	g/kg/d dw	0.2	U.S. EPA (2005); Table C-1-2; composite of all ages

4.2.4 Identification of Exposure Pathways

People can come into contact with chemicals in their environment in a variety of ways, depending on their daily activities and land use patterns. The means by which a person comes into contact with a chemical in an environmental medium are referred to as *exposure pathways*. The means by which a chemical enters the body from the environmental medium are referred to as *exposure routes*. There are three major exposure routes through which chemicals can enter the body: inhalation; ingestion; and dermal absorption (*i.e.*, uptake through the skin). For each of these major exposure routes, there are a number of potential sources of chemical exposure or exposure pathways:

- Direct inhalation of air containing COPCs through the lungs;
- Ingestion of soil, dust, drinking water, garden produce, food; and,
- Dermal absorption from soil, dust and water contact with skin.

Exposure pathways may require direct contact between receptors and media of concern (*e.g.*, incidental ingestion of soil), or may be indirect requiring the movement of the chemical from one environmental medium to another (*e.g.,* the uptake and/or transfer of a chemical from soil into home garden vegetables which are then ingested by an individual).

Based upon the available information associated with the study area, the above considerations, and professional judgment, the exposure pathways to be assessed in this study are summarized below. These exposure pathways are considered possible for Flin Flon and Creighton residents, and all will be evaluated in the HHRA.

<u>Inhalation exposure pathways</u>

- Direct inhalation of COPCs measured in outdoor air; and,
- Direct inhalation of COPCs predicted in indoor air.

<u>Dermal exposure pathways</u>

- Dermal contact with COPCs in outdoor soil;
- Dermal contact with COPCs in indoor dust; and,
- Dermal contact with COPCs in surface water.

<u>Ingestion exposure pathways</u>

- Ingestion of COPCs in outdoor soils;
- Ingestion of COPCs in indoor dust;
- Ingestion of COPCs *via* consumption of backyard garden produce;
- Ingestion of COPCs *via* consumption of local wild plants (*e.g.*, blue berries);
- Ingestion of COPCs *via* consumption of locally caught fish;
- Ingestion of COPCs *via* incidental surface water ingestion while swimming;
- Ingestion of COPCs present in the typical food basket (*i.e.*, groceries); and,
- Ingestion of COPCs in drinking water derived from Flin Flon and Creighton area water resources.

4.2.5 Exposure Scenarios

A key requirement of any HHRA is the ability to evaluate changing levels of exposure under a variety of different scenarios. Exposure scenarios describe the situations and conditions in which receptors may be exposed to chemicals of concern in environmental media. In developing an exposure scenario, a variety of factors are considered including: potential for human access to specific areas or environmental media; physical activities / behavioural patterns; time spent in contact with exposure media (*e.g*., soil); other potential sources of exposure to COPCs; lifestyle factors (*e.g.,* wild berry consumption, fishing, and other uses of natural resources; smoking; diet); and the potential of sensitive sub-populations or sensitive locations within the community (*e.g.,* children at schools, playgrounds; elderly at nursing homes).

In general, while all receptors may potentially be subject to the same, or similar, set of exposure pathways and environmental concentrations, the magnitude of exposure experienced by an individual *via* those pathways is, to some extent, dependent on the behavioural and physical characteristics of that individual.

For the current assessment, several exposure scenarios should developed based on the likelihood that particular activities and behaviour patterns would be applicable to certain groups or subpopulations. These hypothetical scenarios are deliberately selected to be conservative in nature (*i.e.,* reasonable worst case), which ensures that potential exposures to chemicals and the resultant risks are neither overlooked nor underestimated.

Proposed Exposure Scenarios:

Typical Northern Manitoba/Saskatchewan Resident (Regional Background): In this scenario, it should be assumed that exposure to COPCs occurs at typical background (or ambient) levels. Background exposures from a reference area, as well as a general food basket should be incorporated into exposure estimates for this scenario.

Typical Flin Flon / Creighton Residential Scenario: This scenario will consider people who live in the town of Flin Flon, Manitoba and Creighton Saskatchewan. The primary focus of this scenario will be on those “stay-at-home” receptors (*e.g.,* infants, preschool children and adults that care for them, retired persons, *etc*.), since they could incur the highest exposures to residential soils. It will be assumed that these receptors may occasionally leave the home area for such reasons as shopping; visiting, vacations, *etc.* The residential scenario will also look at a subset of the general population (*i.e*., avid anglers and their families) who may consume significantly greater amounts of locally caught fish relative to a typical residential family.

Day Care / School Scenario: This scenario will consider both preschool and older children who may attend day care and/or local schools. While at school or day care, it should be assumed that children may play outdoors and come into contact with native soils and dust. While indoors, children should be assumed to come into direct contact with indoor durst, *etc*.

Parkland Scenario: This scenario will consider individuals who may, on occasion, spend time at local parks and recreational areas within the Flin Flon and Creighton during the spring, summer and fall months. While spending time in these areas, all individuals should be assumed to come into direct contact with surface soils.

Commercial Land Use Scenario: This scenario will consider adults who may spend a significant amount of time at their place of work. While spending time in these areas, all individuals should be assumed to come into direct contact with indoor dust and surface soils while outdoors.

Developing exposure scenarios specific to individual land uses will facilitate the development of property-specific soil standards (PSSSs). As previously indicated, PSSSs are typically defined as the average chemical concentration in soil within a given exposure unit (EU) or area that corresponds to an acceptable level of risk (U.S. EPA, 2001). In other words, the PSSS is the concentration in soil in a defined area (*e.g.,* the community of Flin Flon, Creighton, *etc.*) which would yield an acceptable level of risk. The soil concentrations used to facilitate the long-term (or chronic) exposure assessment and subsequent approximation of risk typically uses an estimate of the average soil concentration from a specific EU (or community of interest). A conservative estimate of the average soil concentration is typically used in HHRA due to the underlying assumption that individuals will tend to move, over a prolonged period of time, in a random fashion over a given EU and, therefore, come into contact with the average soil concentration over a site.

If the PSSS is defined as some estimate of the average soil concentration within a given community which yields an acceptable level of risk, then it is possible that some properties (*e.g.*, individual residential lots, school yards, parks, *etc*.) within the community may exceed the PSSS. If the property or site of concern was a single residential lot, it would be reasonable to assume that an individual would move in random fashion within his or her own residential property. Under these circumstances, a reasonable approach may be to remove highly impacted soil to facilitate the reduction in the average soil concentration of the single property. However, because the exposure units of interest represent entire communities, in which individuals do not move in a random fashion, the remediation of locally impacted zones to reduce the overall concentration for the community is not valid. Hence, the PSSS values should be applied to individual properties, not necessarily the community as a whole. As a result, the development of land-use based PSSSs will allow all properties included in the original soil survey to be screened against health-based PSSS of a specific land use.

4.3 Exposure Assessment

The exposure assessment evaluates data related to all chemicals, receptors and exposure pathways identified during the problem formulation phase of the HHRA. The primary objective of the exposure assessment is to predict, using site-specific data and a series of conservative assumptions, the rate of exposure (*i.e.*, the quantity of chemical and the rate at which that quantity is received) of the selected receptors to the COPCs *via* the various exposure scenarios and pathways identified in the problem formulation step. The rate of exposure to chemicals from many pathways is usually expressed as the amount of chemical taken in per body weight per unit time (*e.g.*, μg chemical/kg body weight/day).

The magnitude of exposure of receptors to chemicals in the environment depends on the interactions of a number of parameters, including:

- The concentrations of chemicals in various environmental media;
- The physical-chemical characteristics of the chemicals of concern, which affect their environmental fate and transport and determine such factors as efficiency of absorption into the body;

- The influence of site-specific environmental characteristics, such as geology, soil type, topography, hydrology, hydrogeology, local meteorology and climatology *etc*., on a chemical's behaviour within environmental media; and,
- The physiological and behavioural characteristics of the receptors (*e.g.,* respiration rate, soils/dusts intake, time spent at various activities and in different areas).

4.3.1 Background Exposure Assessment

All of the COPCs considered in the HHRA are naturally present within the earth's crust, and/or have a number of anthropogenic sources which are not associated with historic fugitive emissions of the facility. As such, everyone is exposed to COPCs from a number of sources, on a daily basis, regardless of where they live. It is therefore important to consider "background" exposures and risks in an HHRA to determine the extent to which residents are more exposed to chemicals than would be expected in the absence of a source of COPCs.

The background exposure assessment for Typical Northern Manitoba and Saskatchewan Residents should be based, to the extent possible, on ambient or regional background concentrations in soil, dust, water, and food. Predicted background exposures can then be compared with the exposures predicted for the town of Flin Flon and Creighton. The background assessment will also serve to approximate an individual's estimated total daily intake (ETDI) from all sources. The derivation of ETDI is considered necessary for COPCs that are assumed to have a threshold mechanism of toxicity. Refer to Section 5.0 for further details regarding threshold *versus* non-threshold mechanism of toxicity.

4.3.1.1 Data Used in Exposure Assessment for Regional Background

The environmental media data to be used in the background exposure scenario should be taken from a reference (or background) site such as Cranberry Portage that has not been impacted by historical facility emissions. The background scenario should include exposure from typical drinking water and dietary intake, as well as country foods that may be consumed by regional residents (*e.g*., fish, blueberries, *etc*.). The exposure equations used for the regional background assessment will be the same as those used to calculate exposure rates of individuals in the town of Flin Flon and Creighton.

4.3.2 Exposure Assessment of Carcinogens

As the health endpoint of concern for carcinogenic chemicals in the HHRA framework is considered to be incremental lifetime cancer risk, the exposure period that is assessed is an assumed lifetime (*i.e.,* typically a period of 70 years is assumed; U.S. EPA, 1989; Health Canada, 2004). However, for exposure periods that comprise less than 70 years (which is generally the case), the exposures must be amortized (or averaged) over the entire lifetime. Thus, if an individual is exposed to COPCs for 5 years, the exposure estimate would typically be multiplied by a factor of 5/70, to yield an amortized exposure estimate, termed a Lifetime Average Daily Dose (LADD). For each exposure calculation involving carcinogens, all five receptor age classes will be evaluated to calculate the LADD.

4.3.3 Deterministic Versus Probabilistic Exposure Analysis

HHRA generally involves assigning numerical values to input parameters in an appropriate exposure or risk model to obtain a quantitative estimate of risk. Numerical values are required for parameters describing contaminant concentrations in environmental media, contaminant fate

and transport, human exposure and toxic response. These values may be measured, assumed, prescribed or based on published literature. Variability and uncertainty in the input parameters or risk model result in variability and uncertainty in the estimate of risk. It is important that uncertainty in the model not be confused with variability. Uncertainty derives from a lack of knowledge. Alternatively, variability in the model describes differences in parameter values such as metal concentrations at different locations within the study area, or differences in body weight or food intake rates for individuals (*i.e.*, population heterogeneity).

Traditional deterministic methods of quantitative risk assessment use single, or "point estimate" values for input parameters and produce a single estimate of risk or hazard. While input parameters may be selected with some knowledge of their inherent variability or uncertainty, a deterministic analysis does not normally provide any information on the variability or uncertainty of the resulting risk estimate. For example, although input values are often selected to represent either average or reasonable maximum exposure conditions, the location of the point estimate of risk in the context of its potential range and distribution cannot be determined directly. A discrete, or deterministic, sensitivity analysis may provide some indication of the potential range of estimated risk values, but the variability of, and hence confidence in, the risk estimate remains unknown.

The outcome of a deterministic risk assessment model does not provide any information on its underlying distribution, nor does it indicate the likelihood that the risk estimates accurately represent upper percentiles or the central tendency (*e.g.,* the mean, mode, median) of the underlying risk distribution. Consequently, it can be difficult to identify instances where the deterministic risk estimate may be over- or understating the actual potential for risk.
In cases where risks to human health estimated using deterministic methods are clearly not negligible or obviously unacceptable, a probabilistic risk assessment (PRA) can be useful to better characterize risk. PRA uses probability distributions to characterize the inherent variability and uncertainty in input parameters, and produces a probability distribution of estimated exposure or risk. The exposure distribution can be directly compared to a toxicity benchmark to estimate the probability of exceedance. As such, a PRA accounts for natural variability and uncertainty to produce estimated probabilities of exceeding toxicity benchmarks or probabilities of effects of differing magnitude. Evaluating, calculating, and conveying the degree and magnitude of variability and uncertainty in each of the components of the risk assessment process provides decision makers and the public with a strong scientific foundation for understanding risk and evaluating the believability of the final risk estimates. Prior to proceeding with a PRA, the risk assessor should consider whether a probabilistic analysis is necessary and/or appropriate, given the objectives of the assessment and the availability of data. A probabilistic analysis necessarily involves a greater commitment of resources to conduct the analysis and to report and present the results.

For the current HHRA, deterministic analyses should be used to characterize the exposures experienced by Flin Flon and Creighton residents. If elevated risks are found under a reasonable maximum exposure scenario, a probabilistic analysis may be considered. However, prior to proceeding with such an assessment, a detailed sensitivity analysis of the deterministic HHRA should be completed in an attempt to first identify those exposure pathways, assumptions and parameters that drive the resulting risk estimates.

4.3.4 Exposure Estimation Methods

Using the appropriate statistic, exposure point concentration (EPC) data for each environmental media and exposure unit (*e.g.*, residential, school, parkland, and commercial land use) should be summarized for each COPC. These data will serve as the starting point of the quantitative exposure assessment. Relevant environmental media include:

- Surface soil;
- Indoor dust;
- Outdoor/Indoor air
- Home grown produce (*i.e.,* fruits, leafy vegetables, root crops);
- Market basket foods (from non-local sources);
- Locally caught fish;
- Locally harvested wild berries;
- Drinking water; and,
- Surface water.

A critical component to any HHRA is chemical characterization. The chemical characterization step involves determining the appropriate chemical concentration in each environmental media in which an individual may reasonably encounter over a prolonged period. This concentration is often referred to as the exposure point concentration (EPC) and makes up a critical component of a chronic exposure assessment. A HHRA will typically employ the 95% upper confidence limit on the arithmetic sample mean (95% UCL) to characterize the EPC for a given exposure unit (U.S. EPA, 2001, U.S. EPA, 1989). The sample mean is based on a collection of samples from the exposure unit (*e.g.*, a contaminated site or property) and therefore, uncertainty exists as to whether the sample mean (the average of all samples taken) is a true reflection of the population mean. As a result, the 95% UCL on the arithmetic mean can be thought of as an upper estimate of the true population mean for a given exposure unit or environmental media. Typically the 95% UCL is calculated for each COPC and environmental media using ProUCL software developed by the U.S. EPA (2004). ProUCL tests the data set for normality, log normality, and gamma distributions using parametric and non-parametric methods to calculate a conservative and stable 95% UCL (U.S. EPA, 2004c).

As measured concentrations of COPCs in all of the above media may not be readily available, EPCs in some environmental media (*e.g.*, indoor air) may need to be estimated. The following subsections briefly describe the calculations, assumptions and rationale used to estimate exposures through various exposure pathways.

4.3.4.1 Outdoor Soil/Indoor Dust Exposure

The intake of COPCs from soil following ingestion depends upon the amount of soil ingested and the amount of COPCs that are bound to soil particles or dissolved within soil pore water.

Surface soil concentrations gathered from the various sampling locations within the study area will be used to derive exposure estimates *via* direct (*i.e.,* incidental soil ingestion, soil dust inhalation, dermal contact with soil) indoor and outdoor soil exposure pathways. Refer to Appendix C for a detailed methodology to collect and analyze indoor dust samples.

The insoluble nature of most metals in soil limits their potential for uptake through the skin. Available data on dermal uptake of metals indicate that uptake rates are low (Paustenbach, 2000). To estimate exposures *via* dermal contact with soil, an estimated area of exposed skin

during the summer and winter months will be derived. Where possible, age-specific (*i.e.*, infant, toddler, children, adolescent, and adult) whole body surface areas will be used in combination with corresponding age-specific body part surface area percentages. During the summer months, a receptor's head, arms, hands, legs and feet will be assumed to be available for dermal contact. During the cooler months, a receptor's head and hands will be considered available for contact with soil and dust, but hands will be assumed to be gloved during winter. In addition, when winter snow coverage occurs, there will be no contact with soils. Using the estimated skin surface area available for dermal contact with soil during the winter and summer months, in combination with a soil/dust adherence, an estimate of the mass of contaminant adhered to the skin on a daily basis, will be obtained. This estimated mass value should then be multiplied by a chemical-specific dermal bioavailability to yield the soil dermal exposure estimate in µg/kg body weight/day.

In the case of dermal exposure from soil and dust on winter days spent outdoors, it will be assumed that a human receptor's hands would not be exposed as they would mostly likely be covered in clothing (*i.e.*, mittens or gloves) when outdoors during these months.

Exposures from incidental soil ingestion will be estimated using a similar approach. Soil/dust ingestion rates, body weights, time activity patterns and chemical-specific oral bioavailabilities will be used to derive exposure levels resulting from soil ingestion.

The effective intake of COPCs from soil ingestion is dependent upon the amount of chemical released from the soil during digestion. This is especially the case for metals. Only metals that are released in soluble form from soil particles into the stomach or intestines during digestion are considered available for uptake. Metals not released from soil are excreted in the feces and do not have the opportunity to cause adverse health effects. Therefore, in assessing exposure and potential human health risks from soil ingestion, it is necessary to consider the amount of chemical that is actually released from the soil into the gut and small intestine, and not just the total amount that is ingested within the soil. Under ambient conditions in soils, most metals are generally insoluble in water and tend to remain bound to soil particles under neutral conditions (pH 6 to pH 8). However, the solubility of most metals increases under acidic conditions. Therefore, given the acidic conditions of the stomach, it is reasonable to expect that a portion of bound metals will be released and become bioaccessible. Site-specific bioaccessibility studies should be conducted as part of this study and these data will be used to determine the bioaccessibility of the COPCs from soil relative to the medium used to derive the toxicological criterion. Refer to Appendix B for the detailed methodology used to conduct a bioaccessibility study.

The following exhibits (algorithms) provided preliminary information with regards to the types of exposure equations that will be used to characterize daily exposures from many of the specific pathways of interest. These equations are standardized equations from U.S. EPA and Health Canada and are commonly used in HHRA studies. As the assessment proceeds, some slight modifications to these equations may be undertaken to account for additional site-specific information.

Incidental Soil and Dust Ingestion

Exhibit 1.0 **Ingestion of Outdoor Soil**

$$EXP_{Ing\ Soil} = \frac{C_{Soil} * SIR_A * RAF_{Soil}}{BW}$$

where:

$EXP_{Ing\ Soil}$	=	exposure *via* incidental ingestion of soil (µg/kg/day);
C_{Soil}	=	concentration of contaminants in soil (µg/g);
SIR_A	=	annualized soil intake rate (g/day);
RAF_{Soil}	=	relative absorption factor for ingested soil (unitless); and,
BW	=	body weight (kg).

The annualized soil intake rate used above is calculated by combining the summer and winter soil intake rates as follows:

$$SIR_A = SIR_{Summer} + SIR_{Winter}$$

where:

SIR_A	=	annualized soil intake rate (g/day);
SIR_{Summer}	=	soil intake rate for summer months (g/day); and,
SIR_{Winter}	=	soil intake rate for winter months (g/day).

The season-specific soil intake rates are calculated based on the Canadian per capita soil intake rates and the exposure frequencies for the summer and winter months as follows:

$$SIR_{Summer} = \frac{SIR_{per\ capita} * EF_S * ED}{AT}$$

where:

SIR_{Summer}	=	soil intake rate during summer months (g/day);
$SIR_{per\ capita}$	=	Canadian per capita soil intake rate (g/day);
EF_s	=	exposure frequency for summer months (days/year);
ED	=	exposure duration (years (length of life stage)); and,
AT	=	averaging time (days).

$$SIR_{Winter} = \frac{SIR_{per\ capita} * EF_W * ED * WA}{AT}$$

where:

SIR_{Winter}	=	soil intake rate during winter months (g/day);
$SIR_{per\ capita}$	=	Canadian per capita soil intake rate (g/day);
EF_W	=	exposure frequency for winter months (days/year);
ED	=	exposure duration (years (length of life stage));
WA	=	winter accessibility factor; and,
AT	=	averaging time (days).

Exhibit 2.0 **Ingestion of Indoor Dust**

$$EXP_{Ing\ Dust} = \frac{C_{Dust} * DIR_{per\ capita} * (EF_S + EF_W) * ED * RAF_{Dust}}{AT * BW}$$

where:

$EXP_{Ing\ Dust}$	=	exposure *via* incidental ingestion of dust (µg/kg/day);
C_{Dust}	=	concentration of contaminants in dust (µg/g);
DIR_A	=	Canadian per capita dust intake rate (g/day);
EF_S	=	exposure frequency for summer months (days/year);
EF_W	=	exposure frequency for winter months (days/year);
ED	=	exposure duration (years (length of life stage));
RAF_{Dust}	=	relative absorption factor for ingested dust (unitless);
AT	=	averaging time (days); and,
BW	=	body weight (kg).

Dermal Contact with Soil and Dust

Exposure to chemicals in soil and dust is estimated separately for indoor and outdoor scenarios. However, the fraction of exposed skin is assumed to be equal for indoor and outdoor conditions during each season. Table 4-8 shows the fraction of skin that is exposed during each season and the number of days within each season.

Table 4-8 Fraction of Exposed Skin

Units	*Spring*	*Summer*	*Fall*	*Winter*[a]	*Prorated*
Fraction	0.150	0.250	0.150	0.050	0.142
Days	61.0	92.0	91.0	121.0	365.0

[a] Winter was defined as times of the year where direct soil contact would be reduce due to snow cover and/or frozen earth.

The prorated fraction of exposed skin is calculated as factor of the number of days per year for each season and the fraction of skin that is exposed during each season as follows:

$$FR_{Pr\ orated} = \frac{(Fr_{Spring} * Days_{Spring}) + (Fr_{Summer} * Days_{Summer}) + (Fr_{Fall} * Days_{Fall}) + (Fr_{W\ int\ er} * Days_{W\ int\ er})}{365}$$

The surface area of exposed skin is calculated by multiplying the prorated fraction of exposed skin (or the annualized fraction of exposed skin) by the receptor-specific total body surface area and a conversion factor to convert m^2 to cm^2.

$$SA_{Exp} = Fr_{Exp} * SA * CF$$

where:

SA_{Exp}	=	surface area of skin in contact with soil (cm^2/event);
Fr_{Exp}	=	fraction of total surface area that is exposed to soil (per exposure event);
SA	=	total surface area (m^2); and,
CF	=	conversion factor (10,000 cm^2/m^2).

The soil adherence factor (outdoors) is calculated separately from the dust adherence factor (indoors) using the values presented in Table 4-9.

Table 4-9 Dermal Loading Factors and Body Surface Areas

Receptor Age Class	*Percentage of Total Body Surface Area*				*Indoor Dust Loading (mg/cm^2)*				*Outdoor Soil Loading (mg/cm^2)*			
	Hands	Arms	Legs	Feet	Hands	Arms	Legs	Feet	Hands	Arms	Legs	Feet
Infant	5.3	13.7	20.6	6.54	0.014	0.004	0.003	0.009	0.11	0.011	0.031	0.018
Preschool child	6.07	14.4	26.8	7.21	0.014	0.004	0.003	0.009	0.11	0.011	0.031	0.018
Child	5.3	12.3	28.7	7.58	0.014	0.004	0.003	0.009	0.11	0.011	0.031	0.018
Teen	5.68	13.1	33.6	6.93	0.014	0.004	0.003	0.009	0.11	0.011	0.031	0.018
Adult	5.2	14.1	31.2	7.0	0.006	0.002	0.002	0.002	0.045	0.014	0.001	0.018

The Area Weighted Outdoor Soil Adherence Factor (AF_{soil}) is calculated as follows:

$$AF_{soil} = (FR_{SA-Hands} * OSL_{Hands}) + (FR_{SA-Arms} * OSL_{Arms}) + (FR_{SA-Legs} * OSL_{Legs}) + (FR_{SA-Feet} * OSL_{Feet})$$

where:

AF_{soil} = area weighted soil adherence factor (mg/cm^2);
$Fr_{SA\text{-}Hands}$ = fraction of total surface area represented by hands;
OSL_{Hands} = outdoor soil loading for hands (mg/cm^2);
$Fr_{SA\text{-}Arms}$ = fraction of total surface area represented by arms;
OSL_{Arms} = outdoor soil loading for arms (mg/cm^2);
$Fr_{SA\text{-}Legs}$ = fraction of total surface area represented by legs;
OSL_{Legs} = outdoor soil loading for legs (mg/cm^2);
$Fr_{SA\text{-}Feet}$ = fraction of total surface area represented by feet; and,
OSL_{Feet} = outdoor soil loading for feet (mg/cm^2).

Using the values presented in Table 4-9, the Area Weighted Indoor Dust Adherence Factor (AF_{dust}) for the female preschool child is calculated as follows:

$$AF_{dust} = (FR_{SA-Hands} * IDL_{Hands}) + (FR_{SA-Arms} * IDL_{Arms}) + (FR_{SA-Legs} * IDL_{Legs}) + (FR_{SA-Feet} * IDL_{Feet})$$

where:

AF_{soil} = area weighted soil adherence factor (mg/cm^2);
$Fr_{SA\text{-}Hands}$ = fraction of total surface area represented by hands;
ODL_{Hands} = indoor dust loading for hands;
$Fr_{SA\text{-}Arms}$ = fraction of total surface area represented by arms;
ODL_{Arms} = indoor dust loading for arms (mg/cm^2);
$Fr_{SA\text{-}Legs}$ = fraction of total surface area represented by legs;
ODL_{Legs} = indoor dust loading for legs (mg/cm^2);
$Fr_{SA\text{-}Feet}$ = fraction of total surface area represented by feet; and,
ODL_{Feet} = indoor dust loading for feet (mg/cm^2).

Dermal Exposure to Outdoor Soil

Exhibit 3.0 **Dermal Contact with Outdoor Soil**

$$EXP_{Dermal\ Soil} = \frac{C_{soil} * SA/BW * AF_{soil} * CF * EF * ED * ABS}{AT}$$

where:

$EXP_{Dermal\ Soil}$	=	dermal exposure *via* direct contact with soil (µg/kg/day);
C_{soil}	=	concentration of contaminant in soil (µg/g);
SA_{Exp}	=	surface area of the skin that contacts the soil (cm^2/event);
BW	=	body weight (kg);
AF_{soil}	=	adherence factor for soil (mg/cm^2)
CF	=	conversion factor (g/mg);
EF	=	exposure frequency (events/year);
ED	=	exposure duration (years (length of life stage));
ABS	=	absorption fraction; this value is chemical-specific; and,
AT	=	averaging time (days).

Dermal Exposure to Indoor Dust

Exhibit 4.0 **Dermal Contact with Indoor Dust**

$$EXP_{Dermal\ Dust} = \frac{C_{dust} * SA/BW * AF_{dust} * CF * EF * ED * ABS}{AT}$$

where:

$EXP_{Dermal\ Dust}$	=	dermal exposure *via* direct contact with dust (µg/kg/day);
C_{Dust}	=	concentration of contaminant in dust (µg/g);
SA	=	surface area of the skin that contacts the dust (cm^2/event);
BW	=	body weight (kg);
AF_{dust}	=	adherence factor for dust (mg/cm^2)
CF	=	conversion factor (g/mg);
EF	=	exposure frequency (events/year);
ED	=	exposure duration (years (length of life stage));
ABS	=	absorption fraction this value is chemical-specific; and,
AT	=	averaging time (days).

Direct Air Inhalation

Exposure to fine particulates should be assessed through inhalation routes in both indoor and outdoor environments as follows:

Inhalation of Fine Particulates – Outdoors

Exhibit 5.0 Inhalation of Fine Particulates in Outdoor Air

$$EXP_{Inh\ OA} = \frac{\left\lfloor C_{Outdoorair} * BR * RAF_{Inh} * (TSO \div CF) * EF_S * ED \right\rfloor + \left\lfloor C_{Outdoorair} * BR * RAF_{Inh} * (TSO \div CF) * EF_W * ED \right\rfloor}{AT * BW}$$

where:

$EXP_{Inh\ OA}$	=	inhalation exposure *via* outdoor air (µg/kg/day);
$C_{outdoor\ air}$	=	concentration of contaminants in outdoor air (mg/m^3);
BR	=	breathing rate (m^3/day);
RAF_{Inh}	=	relative absorption factor *via* inhalation (unitless);
TSO	=	time spent outdoors (mins/day);
CF	=	conversion factor (mins/hr x hrs/day);
EF_S	=	exposure frequency during summer months (days/year);
EF_W	=	exposure frequency during winter months (days/year);
ED	=	exposure duration (years (length of life stage));
AT	=	averaging time (days); and,
BW	=	body weight (kg).

Inhalation of Fine Particulates – Indoors

Exhibit 6.0 Inhalation of Fine Particulates in Indoor Air

$$EXP_{Inh\ IA} = \frac{\left\lfloor C_{Indoorair} * BR * RAF_{Inh} * (TSI \div CF) * EF_S * ED \right\rfloor + \left\lfloor C_{Indoorair} * BR * RAF_{Inh} * (TSI \div CF) * EF_W * ED \right\rfloor}{AT * BW}$$

where:

$EXP_{Inh\ IA}$	=	inhalation exposure *via* indoor air (µg/kg/day);
$C_{Indoor\ air}$	=	concentration of contaminants in indoor air (mg/m^3);
BR	=	breathing rate (m^3/day);
RAF_{Inh}	=	relative absorption factor *via* inhalation (unitless);
TSI	=	time spent indoors (mins/day);
CF	=	conversion factor (mins/hr x hr/day);
EF_S	=	exposure frequency during summer months (days/year);
EF_W	=	exposure frequency during winter months (days/year);
ED	=	exposure duration (years (length of life stage));
AT	=	averaging time (days); and,
BW	=	body weight (kg).

4.3.4.2 Exposure *via* Home Garden Produce and Wild Berry Consumption

Flin Flon and Creighton specific vegetable garden survey data should be used to characterize COPC concentrations in various home-grown fruits and vegetables. The exposures received by people consuming produce depend upon the concentration of the COPCs in the produce and the amount of produce consumed from backyard gardens. The concentrations of COPCs in the garden produce could be predicted using metal-specific uptake factors and measured concentrations of metals in garden soils. However, given that vegetable garden data already exist, uncertainty associated with this pathway will be reduced if the measured COPC concentrations in produce were used directly in the exposure assessment.

Exhibits 7.0 through 10.0 provide the basic equations upon which pathway specific exposure estimates for home grown produce will be generated. The washing and preparation factor will only be applied if the sample preparation does not include these steps.

Exhibit 7.0 **Ingestion of Home-grown Fruits and Vegetables**

$$EXP_{HP} = \frac{\left(EXP_{RV} + EXP_{AGV} + EXP_{F} \right) * EF * ED}{AT}$$

where:

EXP_{HP}	=	exposure from ingestion of home-grown produce (µg/kg/day);
EXP_{RV}	=	exposure from ingestion of home-grown root vegetables (µg/kg/day);
EXP_{AGV}	=	exposure from ingestion of home-grown aboveground vegetables (µg/kg/day)
EXP_{F}	=	exposure from ingestion of home-grown fruits (µg/kg/day);
EF	=	exposure frequency (days/year);
ED	=	exposure duration (years (length of life stage); and,
AT	=	averaging time (days).

Exhibit 8.0 **Ingestion of Home-grown Root Vegetables**

$$EXP_{RV} = C_{RV} * RVIR * RAF_{Food}$$

where:

EXP_{RV}	=	exposure from ingestion of home-grown root vegetables (µg/kg/day);
C_{RV}	=	concentration of contaminant in home-grown root vegetables (µg/g dw);
RVIR	=	home-produced belowground produce (g/kg/day); and,
RAF_{Food}	=	chemical-specific relative absorption factor for food.

Exhibit 9.0 **Ingestion of Home-grown Aboveground Vegetables**

$$EXP_{AGV} = C_{AGV} * AGVIR * RAF_{Food}$$

where:

EXP_{AGV}	=	exposure from ingestion of home-grown aboveground vegetables (µg/kg/day);
C_{AGV}	=	concentration of contaminant in home-grown aboveground vegetables (µg/g dw);
AGVIR	=	home-grown aboveground vegetable consumption (g/kg/day); and,
RAF_{Food}	=	chemical-specific relative absorption factor for food.

Exhibit 10.0 **Ingestion of Home-grown Fruits**

$$EXP_F = C_F * FVIR * RAF_{Food}$$

where:

EXP_F	=	exposure from ingestion of home-grown fruits (µg/kg/day);
C_F	=	concentration of contaminant in home-grown fruits (µg/g fresh weight);
FPLF	=	food preparation loss factor;
FVIR	=	home produced fruit consumption rate (g/kg/day); and,
RAF_{Food}	=	chemical-specific relative absorption factor for food.

Exhibit 11.0 **Ingestion of Local Wild Blueberries**

$$EXP_{WB} = \frac{C_{WB} * FVIR * RAF_{Food}}{}$$

where:

EXP_{WB}	=	exposure from ingestion of local wild blue berries (µg/kg/day);
C_{WB}	=	concentration of contaminant in local wild blue berries (µg/g dw);
FVIR	=	wild berry consumption rate (g/kg/day); and,
RAF_{Food}	=	chemical-specific relative absorption factor for food.

4.3.4.3 Background Market Food Basket Exposure

The general food basket exposure pathway (*i.e.,* the consumption of foods purchased at grocery stores, markets and restaurants) can be a significant source of background exposure to COPCs. Typical background dietary intakes for the COPCs reported in the published literature may be used in combination with site-specific data (*e.g.*, consumption rates and/or residue levels) to estimate daily exposures of individuals as a result of consuming a typical market basket source.

4.3.4.4 Exposure *via* Drinking Water Ingestion

When estimating background exposures to chemicals *via* drinking water, typical Flin Flon and Creighton drinking water concentrations will be used in all scenarios evaluated.

Estimates of exposure to COPCs from consuming drinking water will be calculated by using the equation illustrated in Exhibit 12.0.

Exhibit 12.0 **Ingestion of Drinking Water**

$$EXP_{DW} = \frac{C_{DW} * WIR * \left(EF_S + EF_W \right) * ED * RAF_{DW}}{AT * BW}$$

where:

EXP_{DW}	=	exposure *via* consumption of drinking water (µg/kg/day);
C_{DW}	=	concentration of contaminant in drinking water (µg/L);
WIR	=	intake rate of drinking water (L/day);
EF_S	=	exposure frequency for summer months (days/year);
EF_W	=	exposure frequency for winter months (days/year);
ED	=	exposure duration (years (length of life stage));
RAF_{DW}	=	relative absorption factor for drinking water;
AT	=	averaging time (days); and,
BW	=	body weight (kg).

4.3.4.5 Exposure *via* Ingestion of Locally Caught Fish

Exhibit 13.0 provides the basic equations upon which pathway-specific exposure estimates will be generated for consumption of locally caught fish. It should be noted that the equations used to determine exposures *via* ingestion of all food items are very similar in structure.

Exhibit 13.0 **Ingestion of Local Marine Fish**

$$EXP_{FISH} = \frac{AC_{FISH} \times RAF_{ORAL} \times C_{FISH}}{BW}$$

where:

EXP_{FISH}	=	daily exposure to chemical from ingestion of local fish (µg/kg/day);
AC_{FISH}	=	amount of fish consumed per day (g/day);
RAF_{ORAL}	=	relative absorption factor for ingestion of chemical (unitless);
C_{FISH}	=	concentration of chemical in fish tissue (µg/g); and,
BW	=	body weight (kg).

4.3.4.6 Exposure for Swimming at Nearby Lakes

The method used to predict dermal absorption will be taken from the U.S. EPA Risk Assessment Guidance for Superfund Volume I: Human Health Evaluation Manual (Part E: Supplemental Guidance for Dermal Risk Assessment) (U.S. EPA, 2004a).

Exhibit 14.0 **Dermal Exposure While Swimming**

$$EXP_{Derm\,SW} = \frac{DA_{event} * SA * EV * EF}{BW * AT}$$

where:

$EXP_{Derm\ SW}$	=	daily dermal exposure *via* direct contact with surface water (µg/kg/day);
DA_{event}	=	absorbed dose per event (µg/cm^2-event);
SA	=	exposed surface area (cm^2);
EV	=	event frequency (event/day)
EF	=	exposure frequency (days/year);
BW	=	body weight (kg); and,
AT	=	averaging time (days/year).

Exhibit 15.0 **Incidental Ingestion While Swimming**

$$EXP_{oral\,SW} = \frac{IR_{SW}\ x\ C_{SW}\ x\ ED\ x\ EF}{BW\ x\ AT}$$

where:

$EXP_{Oral\ SW}$	=	daily oral exposure *via* incidental ingestion of surface water (µg/kg/day);
IR_{SW}	=	incidental ingestion rate of surface water while swimming (L/hour);
C_{SW}	=	concentration in surface water (µg/L);
ED	=	event duration (hours/day);
EF	=	exposure frequency (days/year);
BW	=	body weight (kg); and,
AT	=	averaging time (days/year).

4.3.5 Development of the Risk Assessment Modelling Tool

To appropriately evaluate potential exposures to each of the COPCs, it is important to utilize up-to-date information and techniques for estimating exposure and risk.

Exposure estimation in the current HHRA should be facilitated through the use of an integrated multi-pathway environmental risk assessment model. The model should be spreadsheet based (MS Excel). Models of this type have been used on hundreds of peer-reviewed HHRAs, including those conducted for contaminated sites, smelters, refineries, incinerators, landfills and a variety of other industrial facilities. The model should incorporate the latest techniques and procedures for exposure modelling developed by various regulatory agencies (*e.g.*, U.S. EPA, MOE, CCME, Cal/EPA, U.S. EPA Region VI, WHO, *etc*.) and published academic and scientific literature sources.

To ensure transparency in the HHRA, and to facilitate any future regulatory and/or peer reviews of the HHRA, all assumptions, equations, and parameters used in the assessment, as well as sample calculations, should be provided in the HHRA report.

In to addition, for lead exposures, consideration will be given to the use of the IEUBK model, developed by the U.S. EPA. This model is typically used on U.S. Superfund sites for predicting lead exposures in children related to exposure lead-contaminated soils.

4.4 Hazard Assessment Stage

4.4.1 Selection of Toxicity Reference Values for the Assessment

Toxicity is the potential for a chemical to produce any type of damage, permanent or temporary, to the structure or functioning of any part of the body. The toxicity of a chemical depends on the amount of chemical taken into the body (referred to as the "dose") and the duration of exposure (*i.e.,* the length of time the person is exposed to the chemical). For every chemical, there is a specific dose and duration of exposure necessary to produce a toxic effect in humans (this is referred to as the "dose-response relationship" of a chemical). The toxic potency of a chemical (*i.e.,* its ability to produce any type of damage to the structure or function of any part of the body), is dependent on the inherent properties of the chemical itself (*i.e.*, its ability to cause a biochemical or physiological response at the site of action), as well as the ability of the chemical to reach the site of action (*i.e.*, bioavailability). The dose-response principle is central to the HHRA methodology.

There are two main types of dose-response relationships that are typically used for risk assessment of chemicals:

Threshold Response Chemicals: For most effects, it is thought that there is a dose-response threshold below which no adverse effects would be expected to occur. This relationship is true for all chemicals that do not cause cancer by altering genetic material, including most metals. Thresholds are generally assumed for non-carcinogenic effects because, for these types of effects, it is generally believed that homeostatic, compensating, and adaptive mechanisms must be overcome before toxicity is manifested. Exposure limits derived for threshold-response chemicals are called reference doses (RfD), acceptable daily intakes (ADI), tolerable daily intakes (TDI) or permissible daily intakes (PDI) and are generally derived by regulatory agencies such as Health Canada and the U.S. Environmental Protection Agency (U.S. EPA). These values indicate doses of chemicals that individuals can be exposed to on a daily basis over an entire lifetime without appreciable risk of the occurrence of adverse health effects.

Non-threshold Response Chemicals: For these chemicals, it is assumed that there is no dose-response threshold. This means that any exposure greater than zero is assumed to have a non-zero probability of causing some type of response or damage. This relationship is typically used for chemicals, which can cause cancer by damaging genetic material. Under a "no threshold" assumption, any exposure has some potential to cause damage, so it is necessary to define an "acceptable" level of risk associated with these types of exposures. The acceptable level of risk is a policy rather than a scientific decision, and is set by regulatory agencies, as opposed to risk assessors. In most jurisdictions, an incremental lifetime cancer risk (ILCR) level of less than 1-in-100,000 is considered a negligible risk level.

Exposure limits for this project will be selected from reputable regulatory agencies, with recognized experience and expertise in the derivation of exposure limits to protect human health (*e.g.*, Health Canada, U.S. EPA, ATSDR, WHO, Cal EPA OEHHA, OMOE, *etc*). The exposure limits selected for this HHRA will be scientifically defensible and those routinely accepted and used by government departments on HHRAs conducted in Canada and elsewhere. In selecting the limits, the scientific basis and date of last major review will be among the considerations.

4.4.2 Bioavailability

One of the most important factors in determining exposure of target tissues to chemicals, and the body's response, is bioavailability (*i.e.,* the proportion of a chemical dose entering the blood stream following exposure *via* a particular route (*i.e*., oral, inhalation or dermal)). The bioavailability of a chemical defines the fraction of the chemical exposure that is available to produce toxic effects at a particular site of action (*i.e*., target organ). The bioavailability of a chemical is dependent on the chemical form, the environmental medium, the route of exposure, physiological characteristics of the organism at time of exposure (*e.g.*, ingested chemicals may be absorbed to a different extent depending on whether the stomach is full or empty) as well as the tissues/organs with which the chemical must interact as it is passed from the point of entry to the target tissues.

When applying exposure limits, it is necessary to consider the bioavailability of each chemical in the particular study from which the exposure limit is derived, to obtain reasonable estimates of the quantity of the chemical entering the body of study animals or subjects. This allows for the normalization of exposures with respect to exposure route, and comparison of the bioavailable doses to humans with the exposure limits determined from animal studies or human epidemiological data. It is inappropriate to convert exposure estimates to absorbed doses if toxicity values are based on administered doses. However, if an exposure estimate is adjusted for bioavailability then it must be compared to an exposure limit, which is based on an absorbed, rather than an administered dose. Otherwise, the estimation of potential impacts would be incorrect and may underestimate exposure and risk depending on the particular circumstances. Since most exposure limits are based on administered doses, it is not appropriate to consider absolute bioavailability (fraction or percentage of an external dose, which reaches the systemic circulation) in the assessment of exposures in most instances. A better measure may be that of relative bioavailability which can be determined by comparing the extent of absorption among several routes of exposure, forms of the same chemical, or vehicles of administration (such as food, soil, and water). Systemic absorption of chemicals will differ according to whether the dose was received *via* dermal contact, ingestion or by inhalation. In addition, the systemic absorption will differ depending on whether the chemical is delivered in a solvent vehicle, water, soil, food, *etc*.

For some chemicals, exposure limits are not available for all exposure routes of concern, and in these circumstances, exposures limits may be extrapolated. For example, it is common in HHRA to assess the risks posed by dermal absorption of a chemical based on the exposure limit established for oral exposure. The systemic dose absorbed dermally is scaled to the 'equivalent' oral dose by correcting for the bioavailability of the dermally applied chemical relative to an orally administered dose.

The oral bioavailability of chemicals is typically determined from absorption or excretion studies. The bioavailability, expressed as a percentage, is generally assumed to be 100% minus the percent of the ingested chemical excreted unchanged in the feces. In cases where only the fraction of chemical in the urine is reported, this fraction is selected as the minimum oral bioavailability with the maximum being 100%. In the absence of relevant data, this approach is considered to be reasonable, and to reflect the uncertainty in the oral bioavailability of the chemical.

The relative absorption difference between the oral and dermal routes of exposure can be expressed as a relative absorption factor (RAF_{dermal}). This factor, calculated as follows, is applied to dermal exposure estimates to adjust these exposures prior to comparison with oral exposure limits when route-to-route extrapolation is necessary.

$$RAF_{dermal} = \frac{AF_{dermal}}{AF_{oral}} \; x\,100$$

where:

RAF_{dermal}	=	relative absorption factor for dermal exposure (%);
AF_{dermal}	=	the fraction of the applied chemical absorbed through the skin; and,
AF_{oral}	=	the fraction of the ingested chemical absorbed into the bloodstream.

Typically, adjustments of exposure limits for bioavailability are considered for systemic effects (*i.e.*, following entry into and distribution by the bloodstream, as opposed to occurring at the site of entry [*e.g.*, lungs, skin, gut]) when:

- The exposure limit is based on a different route of exposure (*i.e.*, when the criterion is based on ingestion and the exposure routes of interest are inhalation or dermal exposure);
- The medium of administration in the study used to develop the exposure limit results in a different bioavailability than the exposure medium of interest (*e.g.,* ingestion in drinking water *versus* ingestion in soil); or,
- The bioavailability of the chemical, based on the particular study animal/receptor, is different from that of the receptor upon which the exposure limit is based (*e.g.*, the exposure limit is based on a study using mice, the species of interest is human, and there are reported bioavailabilities for both mice and humans).

In these cases, adjustment for bioavailability may be important in determining appropriate toxicological criteria for use in comparing to route-specific exposures, as well as ensuring that comparisons are made for either internal ("bioavailability-adjusted") doses and limits relevant to the species or population being assessed, or route-specific doses and limits. It allows for normalization of exposures with respect to exposure route, the calculation of total exposures through all routes, and allows the bioavailable doses to humans to be compared with bioavailable doses determined from animal studies.

A detailed site-specific *in vitro* oral bioaccessibility study will be conducted for those COPCs selected for evaluation under the detailed HHRA. The site-specific bioaccessibility studies will help address the differences in oral bioavailability observed in soil *versus* the medium used in the study from which the toxicological criterion was derived. The protocol for this study is presented in Appendix B.

In addition to performing site-specific bioaccessibility studies, the consultant should review the scientific and regulatory literature to identify other available bioavailability information for each route of exposure evaluated in the HHRA. Where possible, values specific to species (*i.e.,* humans) and to the environmental media of concern (*e.g.,* soil, water), and form of metal will be focused on.

4.4.3 Speciation

The geological history of the Flin Flon/Creighton area, and the highly mineralized nature of the area, will likely have significant implications on the form in which many of the COPCs will be available for potential exposure. The occurrence of metals in the environment related to natural deposits versus those arising from smelting and processing activities are likely to be different in structure which may require specific methodologies to address each particular form (*e.g.*, soluble forms, sulfides, subsulfides, and oxides). The process of determining the actual form of metals present within a specific soil sample is typically referred to as speciation. This is relevant to the assessment of risks because the form of a metal in soil can have an important impact on its bioavailability and toxicity to human health. Due to their chemical structure, insoluble forms of metals are less available for uptake into biological systems than more soluble forms which may be readily absorbed.

It may be beneficial to collect samples from a variety of different soil types and geographical locations to provide a complete speciation breakdown representative of soils in the study area. These data can be used in the HHRA to provide a more accurate reflection of the bioavailability and toxicity of specific metals to humans. Samples can be obtained through field sampling or from existing archived soil samples. For example, the speciation of lead can sometimes help to determine whether lead present in house-dust has originated from paint chips containing lead or some other outdoor source. As another example, it is widely accepted that different forms of arsenic have different toxicological significance to humans. Organic forms of arsenic typically found in biological samples are much less toxic relative to inorganic forms found in soil. It is noted that data are readily available to determine the relative speciation of arsenic in these types of media. As a result, speciation of arsenic in environmental media is generally not required. It is noted that arsenic speciation is a critical component to urinary arsenic studies which may be beyond the scope of the current project.

4.5 Risk Characterization Stage

4.5.1 Calculation of Risk Levels

The risk characterization step integrates the exposure and hazard assessments to provide a conservative estimate of human health risk for the receptors assessed in the various exposure scenarios. Potential risk will be characterized through a comparison of the estimated or predicted chronic exposures from all pathways (from the Exposure Assessment) with the identified exposure limits (from the Hazard Assessment) for all chemicals of potential concern.

For the COPCs which are non-carcinogens, this comparison is typically called the Exposure Ratio (ER) or Hazard Quotient (HQ) and will be calculated by dividing the predicted exposure level by the exposure limit (see equation below).

$$\text{Exposure Ratio (ER)} = \frac{\text{Estimated Exposure (ug/kg/day)}}{\text{Exposure Limit (ug/kg/day)}}$$

Risk characterization for chemicals with a non-threshold-type dose response (*i.e.,* carcinogens) consists of a calculation of the Incremental Lifetime Cancer Risk (ILCR), which is defined as the predicted risk of an individual in a population of a given size developing cancer over a lifetime. The ILCR is expressed as the prediction that 1 additional person per ***n*** people would develop cancer, where the magnitude of ***n*** reflects the risks to that population; for example, if the ILCR is 1 person per 10, the predicted risks of any individual developing cancer would be higher than if

the ILCR is 1 per 1,000. The following equation provides the method whereby the ILCR is calculated:

Incremental Lifetime Cancer Risk (ILCR) = Estimated Lifetime Exposure x Cancer Slope Factor (q_1^*)

The resulting estimated cancer risk can then be compared to an acceptable risk level of cancer to determine if exposures to the assessed chemical pose an unacceptable health risk. In the Province of Manitoba and Saskatchewan, the acceptable risk level is 1-in-100,000.

For chemicals with similar critical effects (*i.e.*, those that act *via* a similar toxicological mechanism on a similar target tissue), individual ERs or ILCRs will be summed to reflect the combined risk level. Where COPCs have both cancer and non-cancer endpoints, risk estimates will be determined for both endpoints. The more sensitive of the two endpoints will be used to calculate land use specific PSSS for that particular COPC.

In addition to the assessment of risks resulting from chronic, multi-media exposures, acute or short-term risks associated with the inhalation of COPCs in ambient air will be assessed through comparison with short-term (*i.e.*, 1 hour or 24 hour) air quality guidelines.

4.5.2 Consideration of Chemical Mixtures

Concurrent exposures to more than one chemical may result in toxicological interactions leading to several different possibilities in terms of combined toxicity. The combined toxicity may simply equal the sum of toxicities of the individual chemicals (additivity or independence), or may be greater (synergism or potentiation) or less than (antagonism) the sum that would be expected for additive or independent toxicity. In general, toxicological interactions depend on the chemicals present, the levels of exposure to each, their mode of action and their concentrations. Most non-additive interactions can only be demonstrated at relatively high exposures, where clear adverse effects are observed. Such interactions have not been observed or quantified at the relatively low rates of exposure typical of those associated with most environmental situations (NAS, 1983; Krewski and Thomas, 1992). Based on this, and evidence which suggests that zinc may modify lead uptake in children (by significantly reducing uptake of lead) (Noonan *et al*, 2003), a summary of the scientific literature will be provided on possible effects of mixtures for the COPCs which are considered in the HHRA.

4.5.4 Sensitivity Analysis and Identification of Uncertainties and Limitations

A sensitivity analysis of the HHRA pathways should be conducted to determine the relative contribution to total exposure from the various exposure pathways. This information will be critical for decision-making related to the need for and possible effectiveness of risk management, if deemed necessary. In addition, key uncertainties and limitations will be identified in the HHRA report, and their effect on the HHRA results should be discussed in the report.

4.6 Risk Management and Remedial Objectives

As previously indicated, one of the primary objectives of the HHRA is to characterize the potential human health risks of individuals living in Flin Flon and Creighton as result of exposures to elevated levels of metals found in various local environmental media. Risks can be characterized based on exposure to levels of COPCs in various exposure units. Exposure

units can be defined as a single residential property or an entire community such as Flin Flon or Creighton. The underlying assumption used when developing a chronic (or long-term) exposure scenario is that individuals will, over time, move randomly within each exposure unit and, therefore, over time, come into contact with the average soil concentration within a given exposure unit. If the exposure unit of concern were a single residential lot, it would be reasonable to assume that an individual would move in a random fashion within his or her own property. In reality, individuals do not move in a random fashion within their community, but rather exhibit predictable spatial patterns in their movements. For example, many individuals will tend to spend the majority of their time between home and work or school. Therefore, the evaluation of risk on the basis of the EPC (assuming random movement) in an area-wide risk assessment (such as an entire community) may underestimate risks for some receptors. As a result, in area-wide assessments, where data permits, a number of different exposure units should be assessed (*e.g.*, residential, parkland, schools, *etc*.) with the intent of developing PSSs for each exposure unit or land-use (*e.g.*, residential, parkland, schools, *etc*.).

Property specific standards are chemical concentrations in soil that are protective of human health under specific land use assumptions and are derived through the use of a 'forward facing' risk assessment. For example, a HHRA of residential properties in the area could be conducted using an estimate of the average residential soil concentration within the community. Although no unacceptable human health risks may be observed using the average (*i.e.*, the 95% UCL) residential soil concentration, there may be some properties or even streets within the community that have soil concentrations that exceed the residential community average. Therefore, in order to capture those properties or streets that may have soil concentrations above the community average, a property-specific health based soil standard can be derived which will be protective of human health under a residential land use scenario. This residential health-based standard is used to screen against the subset of properties within the community that were sampled to ensure that no individual properties exceed the property specific health based standard.

4.7 Schedule of Tasks and Deliverables

Table 4-10 provides a tentative schedule of tasks and deliverables associated with the completion of the HHRA. All dates are subject to change and are largely dependent on the timing of Task 3 (Phase II soil and data collection). Certain tasks/subtasks may not be deemed necessary, such as the review of the HHRA by a peer review panel or the additional collection of certain environmental media. Others may not require a meeting or the submission of a separate report to the TC or CAC (*e.g.*, the exposure assessment/risk assessment model).

Table 4-10 Tentative Schedule of Tasks and Deliverables Associated with the Completion of the HHRA

TASK/Deliverable	*Tentative Date of Delivery to TC/CAC*	*Tentative Meeting Date*
1. Data Review	September 21, 2007	October 1, 2007
2. Terms of Reference/HHRA Methods	October 15, 2007	November 1, 2007
3. Supplemental Data Collection • Soil/dust • Blueberries • Fish • Bioaccessibility • Speciation	November 30, 2007	
4. Problem Formulation	December 15, 2007	January 7, 2008
5. Exposure Assessment/RA Model	NR	NR
6. First Draft Report/Preliminary Results	March 15, 2008	April 1, 2008

Table 4-10 Tentative Schedule of Tasks and Deliverables Associated with the Completion of the HHRA		
TASK/Deliverable	***Tentative Date of Delivery to TC/CAC***	***Tentative Meeting Date***
7. Second Draft (for Peer Review)	May 15, 2008	June 1, 2008
8. Peer Review Panel		
9. Final Draft	July 15, 2008	August 1, 2008
10. Final Report/Public Communication	September 15, 2008	October 1, 2008

NR A meeting or the submission of a separate report may not be required for this task.

5.0 REFERENCES

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