CHAPTER 1

INTRODUCTION AND GENERAL METHODOLOGY

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Table of Contents

Page

1.0 INTRODUCTION AND GENERAL METHODOLOGY 1-1
1.1 Human Health Risk Assessment (HHRA) 1-2
1.2 The HHRA Framework.. 1-3
1.3 Study Objectives.. 1-5
1.4 Background Information.. 1-6
1.5 Study Scope 1-8
1.6 Elements Considered Outside the Study Scope.. 1-14
1.7 A Phased Approach to the HHRA 1-15
1.7.1 Phase 1 – Literature Review, Data Gap Analysis and Supplemental Sampling 1-15
1.7.2 Phase 2 – Problem Formulation.. 1-16
1.7.3 Phase 3 – Detailed HHRA 1-17
1.8 References 1-18

List of Tables

Table 1-1 Summary of Data Gaps and Recommendations.. 1-16

List of Figures

Figure 1-1 Factors Required for a Risk of Health Effects.. 1-4
Figure 1-2 Overview of the Risk Assessment Framework 1-5
Figure 1-3 Map of Area Sampled During the Manitoba Conservation Soils Study 1-8

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1.0 INTRODUCTION AND GENERAL METHODOLOGY

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 sulphur and 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.

Intrinsik Environmental Sciences Inc. (Intrinsik) was retained by HBMS to conduct this 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. A Technical Advisory Committee (TAC) was formed to provide technical guidance to this process. The TAC is comprised of representatives of HBMS, Health Canada, Saskatchewan Environment, Saskatchewan Health, Manitoba Conservation, Manitoba Health, Manitoba Water Stewardship, and Manitoba Innovation, 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 comments from members of the public, and to demonstrate how HBMS uses that input in the decision making process. Many sections of this report were subject to TAC review and have been modified to reflect these comments.

The HHRA report contains the following Sections and Appendices:

Chapter 1 – Introduction and General Methodology;
Chapter 2 – Literature Review, Gap Analysis and Supplemental Sampling;
Chapter 3 – Problem Formulation;
Chapter 4 – Detailed Human Health Risk Assessment Methodology;
Chapter 5 – Results and Discussions;
Chapter 6 – Other Risk Assessment Issues;
Chapter 7 – Limitations and Uncertainties in the Human Health Risk Assessment;
Chapter 8 – Conclusions and Recommendations;
Appendix A – Toxicological Profiles:

- A1 – Arsenic;
- A2 – Cadmium;
- A3 – Copper;
- A4 – Lead;
- A5 – Mercury; and,
- A6 – Selenium.

Appendix B – Residential Soils Study;
Appendix C – Literature Review, Data Gap Analysis, and Supplemental Data;
Appendix D – Dust Study and Results;
Appendix E – Surface Water, Sediment, Fish and Blueberry Study;
Appendix F – Response to TAC Comments on the HHRA;
Appendix G – Bioaccessibility;
Appendix H – Worked Example;
Appendix I – Correlation of Metal Content in TSP and PM_{10};
Appendix J – Glossary of Terms;
Appendix K – Market Basket Estimated Daily Intake (EDI);
Appendix L – IEUBK Modelling Results;
Appendix M – Detailed Results;
Appendix N – ProUCL Results for the Derivation of Exposure Point Concentrations (EPCs);
Appendix O – Methods Used to Estimate Wild Game Tissue Concentrations for the Human Health Risk Assessment;
Appendix P – Food Consumption Survey;
Appendix Q – Metals in Drinking Water;
Appendix R – Snow Column Sampling;
Appendix S – IERP Review of the HHRA; and,
Appendix T - Response to IERP Comments on the HHRA.

1.1 Human Health Risk Assessment (HHRA)

An HHRA is a scientific study that evaluates the potential for the occurrence of adverse health effects from exposures of people (receptors) to chemicals of concern (COC) present in surrounding environmental media (*e.g.*, air, outdoor soil, indoor dust, surface water, food and biota, *etc*.), under existing or predicted exposure conditions. HHRA procedures are based on the fundamental dose-response principle of toxicology. The response of an individual to a chemical exposure increases in proportion to the chemical concentration in critical target tissues where adverse effects may occur. The concentrations of chemicals in the target tissues (the dose) are determined by the degree of exposure, which is proportional to the chemical concentrations in the environment where the receptor resides, works or visits.

The Flin Flon HHRA has been conducted in accordance with the regulatory guidance provided by Health Canada (1993; 2004, 2006) and is primarily based upon guidance developed as part of the U.S. EPA Superfund program (U.S. EPA, 1989; 1992; 1997; 1999; 2001a,b; 2002; 2004). Guidance provided by the Ontario Ministry of the Environment (O. Reg. 153/04; OMOEE, 1997 and related documents) and the CCME was also considered. The current study was considered to be an area-wide risk assessment, as it evaluated a large geographical area, rather than an individual property (that would be considered a site-specific risk assessment or SSRA). The main advantage to this approach is that it allowed for the estimation of potential health risks across a broad area, and evaluated potential exposures from a variety of input sources (*e.g.*, smelter emissions, locally grown foods, regional drinking water, *etc*.). However, this approach also required considerably greater amounts of data specific to the Flin Flon area.

While many of the elements of an area-wide assessment have their roots in the approaches used to evaluate risk on a site-specific basis, it is important to note that there is no specific regulatory guidance available governing area-wide risk assessment in Canada. It must also be recognized that an HHRA is not the same as a community health study. Community health studies may involve such tasks as questionnaires, interviews, medical records review, and collection of biological tissue or fluid samples (*e.g.*, blood, urine, hair) to directly measure human exposures. While these types of information can be valuable supplementary information for an HHRA, they are not components of the established HHRA framework that is described below.

The following sections describe the HHRA framework and methodology used in the HHRA for the Flin Flon area.

1.2 The HHRA Framework

The fundamental purpose of an HHRA is to estimate whether people working, living or visiting a given location are being exposed, or will be exposed, to concentrations of chemicals that have the potential to result in adverse health effects. The assessment of potential occurrences of adverse health effects from chemical exposure is based on the dose-response concept that is fundamental to the responses of biological systems to chemicals, whether they are therapeutic drugs, naturally-occurring substances, or man-made chemicals in the environment. Thus, an HHRA evaluates the likelihood (or risk) of adverse health effects following chemical exposures. It requires consideration of the toxic properties of the chemicals, the presence of receptors, and the existence of exposure pathways to the receptors. When all three factors are present (*i.e.*, chemicals, receptors and exposure pathways), there is a potential for adverse health effects to occur if exposures to the chemicals are elevated above acceptable levels (See Figure 1-1).

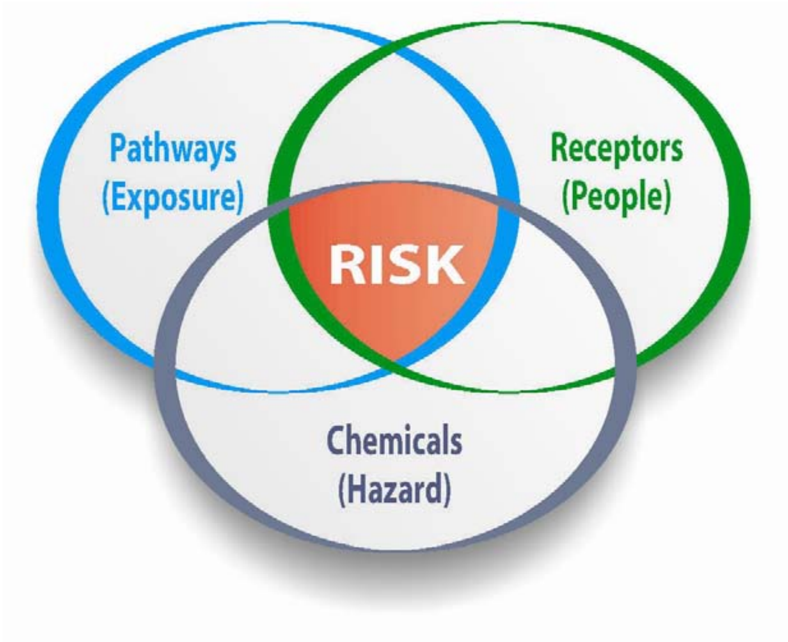

Figure 1-1 Factors Required for a Risk of Health Effects

The current framework used to evaluate potential environmental and human health risks has evolved considerably from its roots in the 1983 regulatory document, "Risk assessment in the federal government: Managing the process", released by the United States National Research Council (NRC, 1983). Although there are slight variations between different jurisdictions with respect to how HHRAs are conducted, the key elements of the HHRA framework are highly consistent across most agencies in their respective jurisdictions.

The current HHRA followed the standard HHRA framework (see Figure 1-2) that is composed of the following steps:

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

Typically, where potential adverse impacts are predicted through risk characterization, an additional step providing risk management recommendations to address these concerns can be added, if necessary.

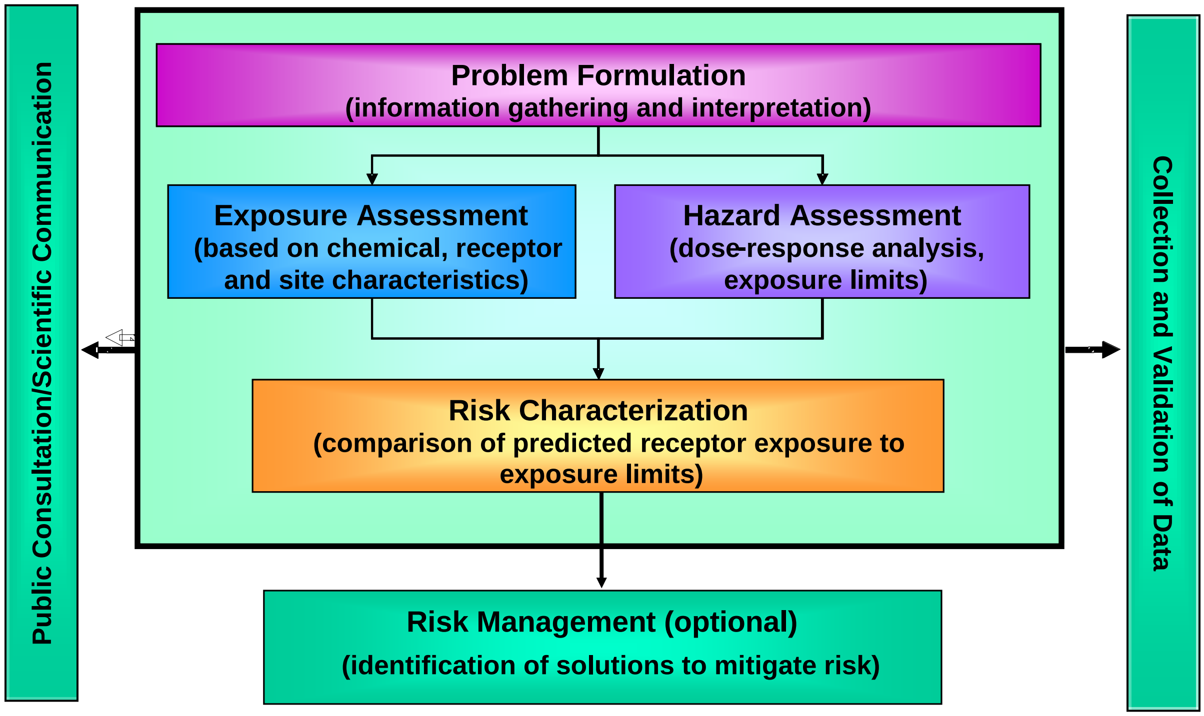

Figure 1-2 Overview of the Risk Assessment Framework

Within these four steps, HHRAs typically include the following key components and concepts:

- A multimedia approach which considers total exposure from all relevant environmental media. This approach recognizes that contaminants may be present simultaneously in food, air, water, consumer products, soil or dust;
- Exposure pathway identification and analysis;
- Receptor identification and characterization;
- Assessment of the bioaccessibility/bioavailability of COC;
- Toxicological assessment of COC; and,
- Should they be required, the development of health-based site-specific intervention levels and/or other risk management activities (*e.g*., decreasing bioavailability of metals, blocking exposure pathways), which can be used to establish remedial action levels or other risk management goals on a community and area-wide basis that will be protective of human health, now and in the future.

1.3 Study Objectives

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 Provisional Trigger Concentrations (PTCs) for residential soil for each COC. PTCs can be applied on a property-by-property basis to determine which properties may have concentrations of COC in soil that may require risk management or further consideration such as biomonitoring of residents.

1.4 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 with the distribution of zinc exceeding lead, which in turn exceeded the distribution of arsenic and copper (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 1-3). 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.

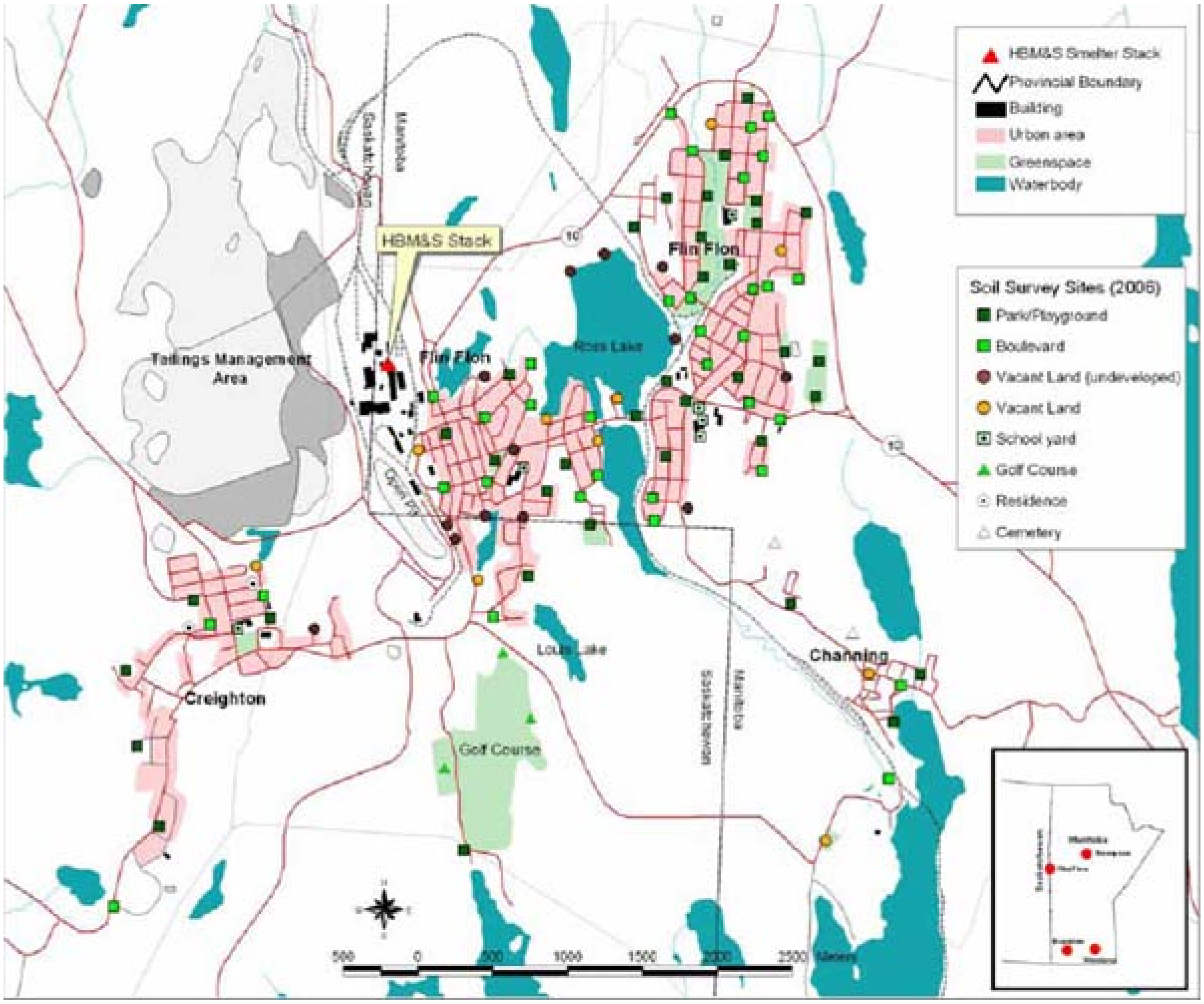

Figure 1-3 Map of Area Sampled During the Manitoba Conservation Soils Study (Bakers Narrows Provincial Park and Cranberry Portage are not Shown) (Manitoba Conservation, 2007)

In addition to the surface soils study, Manitoba Conservation has conducted three other 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 (Chapter 3). Details regarding the available data describing the metal content of various environmental media in the Flin Flon and Creighton area are provided in the Literature Review, Data Gap Analysis and Supplemental Sampling section of this report (Chapter 2).

1.5 Study Scope

This HHRA study is a detailed, comprehensive study, which evaluates a number of exposure pathways, chemicals and receptor groups. The specific study components are outlined here and are discussed in greater detail in Sections 3 and 4 of this document.

Time Scale of Risk Assessment

This study provides an evaluation of current metal exposures and projected estimated risk levels into the future (*i.e.*, lifetime exposures) based on current soil chemical concentrations. The HHRA does not evaluate historical impacts of, or risks related to, historical metal exposures. Given that historic air emissions were elevated relative to current levels, exposure and risk levels during previous years would be higher for long-term residents that have been living in the Flin Flon area relative to the predicted current and future risk levels. The findings of the Community Health Status Assessment of Flin Flon and Creighton, completed by public health officials from Manitoba Health and Healthy Living and the Saskatchewan Ministry of Health, should be considered in the evaluation of risks to long-term residents exposed to historic air emissions.

Outdoor Soil and Indoor Dust 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 concern (COC) 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 using generic assumptions, 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, an additional soil and dust sampling program was completed. This program included the collection of soil samples from the front and backyards of residential properties, as well as the collection of residential indoor dust. As part of this program, select outdoor soil samples were submitted for specialized analysis to determine the bioaccessibility of certain metals to allow for a more accurate prediction of exposure.

The supplemental sampling program conducted for residential locations in the Flin Flon and Creighton area is outlined in Chapter 2, Section 2.0. Further details are provided in Appendix B. Soils were analyzed for selected metals of interest (see below). Additional soil samples from selected areas were subjected to bioaccessibility testing using an *in vitro* stomach/intestinal leach protocol (see Appendix G), to determine the relative bioaccessibility of the metals of interest within soil and dust.

Selection of Chemicals of Concern (COC)

The selection of the COC for the HHRA was based on concentrations of chemicals measured in surface soil as part of the Manitoba Conservation (2007) study and the supplemental residential sampling conducted as part of this study (Jacques Whitford, 2008). Although soil data collected as part of additional studies completed by Manitoba Conservation which focused on forest soils, blueberries, and home garden produce were considered, data collected during the surface soils studies was considered to be the most relevant to the HHRA. Chapter 3, Section 3.2.4 provides the screening process used in the selection of COC.

<u>*Selection of Receptors*</u>

In keeping with risk assessment procedures widely used in Canada, receptors in five age categories (*i.e*., infant, toddler, child, teen, and adult) were assessed within the current HHRA. Overall, the toddler is generally regarded as being 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) was evaluated for any carcinogenic chemicals requiring assessment. The receptor characteristics applied in this assessment are discussed in further detail in Chapter 3, Section 3.3 of this document.

<u>*Selection of Exposure Pathways and Supporting Rationale*</u>

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

<u>Outdoor Soil</u>: Direct exposure to COC in soil was 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 were evaluated using soils data collected as part of the Manitoba Conservation soils study and additional data collected during the supplemental residential study (Appendix B).

<u>Indoor House Dust</u>: 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 was 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 using generic assumptions, it is preferred to use actual measured concentrations collected from various hard and soft surfaces within homes. Dust was collected as part of the supplemental residential sampling conducted as part of this study (Appendix B). Interpretation of this data is provided in Appendix D.

<u>Home Garden Produce</u>: Studies conducted by HBMS (1994), Pip (1991), and Manitoba Conservation (Jones and Henderson, 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, Jones and Henderson (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 (Jones and Henderson, 2006). Overall, the Jones and Henderson (2006) 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 (Jones and Henderson, 2006). Of these three primary studies, Jones and Henderson (2006) served as the primary source of home garden produce data for the HHRA.

Although data from the Pip (1991) and HBMS (1994) studies were considered, the data provided within the Jones and Henderson 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, 2007). 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 was distributed to residents of Flin Flon and Creighton in early 2008 to gather information on fishing, hunting, and wild berry collecting patterns. Residents were asked to provide information on where they obtain local berries from and to indicate which family members consume local berries and an estimate of the amount consumed. The results of this survey indicated that the consumption of local berries collected from areas impacted by smelter emissions is a potentially significant source of exposure, and as a result, an additional sampling program was completed in which blueberries were analyzed for all chemicals retained as COC for the HHRA (Appendix E). The collection of samples was limited to a few areas where blueberries are 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 locations were identified, it provided an accurate representation of the blueberries that the general population will be consuming (Appendix E).

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 is a potentially significant route of exposure to metals released by the HBMS complex. Historically, 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 was limited recent data provided for fish from lakes that are likely to be used for recreational fishing, a supplemental study was conducted to collect fish from area lakes (Appendix E).

As discussed for blueberries, to help address uncertainties, the local food survey distributed to residents of Flin Flon and Creighton in early 2008, gathered information on fishing, hunting, and wild berry collecting patterns. Residents were asked to describe the species and sizes of fish consumed and the most common locations they are taken from. Residents were also asked to indicate which family members consume local fish and the number of meals consumed per week for different seasons throughout the year. Since the survey indicated 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 was completed in which the edible muscle tissues were analyzed for all chemicals retained as COC for the HHRA (Appendix E).

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 supplied water from Trout Lake (also called Embury Lake) through active pumping. Drinking water for Creighton is taken from Douglas Lake. Provided as part of a Manitoba Conservation sampling program for drinking water in Flin Flon, 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 (2006) indicate that similar concentrations are found in drinking water supplied to the residents of Creighton.

HBMS provided measured concentrations of each COC in drinking water collected on a bi-weekly basis from August 2007 to July 2008 for three locations in Flin Flin and two locations in Creighton. These data are considered to be representative of any potential variability in drinking water quality that may result from seasonal fluctuations occurring in the source water body. Since there is a limited number of sample locations included within this program, members of the Technical Advisory Committee (TAC) decided that an additional short-term study in which multiple locations throughout Flin Flon and Creighton were included in a one-day sampling event should be completed to ensure that these data were representative of drinking water quality throughout the communities. Jacques Whitford (2008) conducted a residential drinking water sampling program on a number of homes, schools, and daycares in Flin Flon (36) and Creighton (11) on March 6 and 7, 2008 to assess the current metal status of tap drinking water. For residential locations and daycares, flushed drinking water samples were collected from the most frequently used tap, typically the kitchen. In schools, flushed water samples were collected from a public water fountain (Jacques Whitford, 2008).

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 COC 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, TSP data measured at the Provincial Building was used to estimate concentrations of COC within the PM_{10} component. Given the location of this sampling station, this data was used for predicting inhalation exposure to residents living within the community of West Flin Flon. The HBMS-operated samplers at Ruth Betts and Creighton School 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 COC 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 COC 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 COC 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 COC concentrations in indoor air are not available, a methodology for estimating these concentrations must be developed. Within the Integrated Exposure, Uptake, and Biokinetic model (IEUBK 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 COC has not been established. As a result, it was conservatively assumed that concentrations in indoor air were equal to concentrations measured within the PM_{10} component of outdoor air.

Surface Water: The natural abundance of lakes in the Flin Flon-Creighton area provides the opportunity for many water-based recreational activities. As a result, the HHRA evaluated the potential exposure and risk levels associated with swimming in surface water of lakes throughout the study area. During the completion of the fish study conducted by Stantec (2009) in the summer of 2008, surface water samples were collected and analyzed for each COC. Additional surface water samples were also collected by Manitoba Water Stewardship and were combined with the Stantec data to form one larger data set (Appendix E).

Market Basket 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 the Canadian Environmental Protection Act (CEPA) Priority Substance List reports, ATSDR toxicological profiles, World Health Organization (WHO) Environmental Health Criteria monographs, Total Diet Study (TDS) Programs conducted by Health Canada and the U.S. Food and Drug Administration (FDA), and the primary scientific literature. For this HHRA, these sources were reviewed, and relevant data on the dietary concentrations of the COC were 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*. (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 TDS 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 U.S. since 1961, and this data source was also reviewed and considered for use in the risk assessment. The most appropriate of these information sources was used to characterize background exposures to the metals of interest, *via* the diet.

1.6 Elements Considered 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 has been assumed 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 are no human exposure pathways to metals in groundwater in this area, exposure to metals in groundwater was not evaluated in the HHRA.

Occupational Exposure at the Mine or Smelter

One concern raised during the initial stages of the process was whether the HHRA would consider the impacts of occupational exposures on the overall health of community members, and whether this would make workers a particularly sensitive subpopulation within the overall community. This exposure scenario, considering local residents who are additionally exposed to the COC at their workplace (*e.g.,* in the mines or at the smelting/processing facilities) was not evaluated. Assessments of occupational exposures are outside the scope of the HHRA. Occupational exposure studies are dealt with by the HBMS medical departments and the Joint Occupational Health and Safety Committee.

When discussing this issue, it is important to understand that the HHRA was not designed or intended to examine occupational exposure to metals in the workplace. There are several reasons for this. Occupational exposure is a matter addressed by the Joint Health and Safety Committee that is composed of company and union representatives, among others. HBMS has programs in place that examine and measure a worker's exposure to the COC being addressed by the HHRA. Most importantly, different levels of "acceptable" risk are assumed for employees in the workplace compared to a resident of the general population exposed to metals in the environment. The level of "acceptable" risk to the resident is much lower, therefore, the standards being applied in this HHRA are more rigorous than those that would be applied in an occupational setting. Additionally, occupational concerns lie with the worker, typically a healthy adult, while risk assessments, by definition, protect sensitive individuals within the population (*e.g.,* children, pregnant women, the elderly, those with compromised health).

Other concerns that may be associated with occupational contact with the COC will be considered within the assessment. As part of the indoor dust survey, occupational information was gathered on all members of the evaluated households. Any association between COC concentrations and employment by HBMS will be noted. Past projects have concluded that improved industrial hygiene and housekeeping procedures have limited the amount of COC which are transported from the workplace to the home.

1.7 A Phased Approach to the HHRA

The HHRA framework was applied in three distinct phases:

Phase 1 – Literature Review, Data Gap Analysis and Supplemental Sampling;
Phase 2 – Problem Formulation; and,
Phase 3 – Detailed HHRA.

The phased approach allowed the HHRA to proceed in a logical and sequential manner, and allowed for unresolved issues or major uncertainties to be addressed as they were identified. A phased approach also allowed for multiple iterations of the HHRA, such that various components of the HHRA were efficiently revisited and re-evaluated as new information became available.

A brief introduction of key activities within each phase is provided below. Subsequent chapters (*i.e.*, Chapters 2 through 4) describe each phase in detail.

1.7.1 Phase 1 – Literature Review, Data Gap Analysis and Supplemental Sampling

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 additional sampling needs in order to adequately assess exposure and risk to people in the affected areas. This Phase provides a summary of the literature reviewed as well as a data gap analysis for information relevant to the HHRA. Information gathered describing metal content in soil, ambient air, home garden produce, drinking water, fish and sediment, surface water, and local blueberries, were reviewed. This chapter summarizes all literature and data obtained prior to and in support of the HHRA.

Based on a preliminary review of the available resources, the collection of supplemental data was recommended to reduce uncertainty associated with predicting exposure to metals in certain environmental media (Table 1-1). While concentrations in soil have been well characterized to accurately predict outdoor exposure in public areas, the collection of data from the front and backyards of residential properties as well as dust from indoor environments was deemed necessary. As part of an additional outdoor soil and indoor dust sampling program, laboratory analysis of select samples to determine the bioaccessibility of certain metals allowed for a more accurate prediction of available dose.

To address data gaps in ambient air data, HBMS expanded the list of chemicals analyzed in the PM_{10} component of samples. Although HBMS has tested for all 11 metals of concern associated with PM_{10} at the Ruth Betts and Creighton Schools, the absence of these data from the Provincial Building created an area of uncertainty for the HHRA given that concentrations may be the highest at this location. The home garden study conducted by Manitoba Conservation (2007) included a significant amount of information related to concentrations of metals in produce. Data provided as part of this study is considered to be sufficient to accurately assess this exposure pathway with some potential uncertainty associated with characterizing home garden produce in Creighton. HBMS has addressed gaps in drinking water data by sampling water from residential locations in Flin Flon and Creighton.

A lack of data describing metal content in the edible tissues of local fish resulted in the need for the completion of an additional study in the summer of 2008. Concentrations of metals in fish tissue, surface water, and sediments were collected from a number of lakes throughout the Flin Flon-Creighton area that are used frequently for recreational activities.

Finally, information regarding concentrations of metals in local blueberries were essentially limited to lead and mercury, which were nearly all below detection. However, there was limited information to indicate that concentrations of lead and several other metals may be elevated at sites located in close proximity to the smelter. Given that it is common for some residents of Flin Flon and Creighton to pick large amounts of blueberries for personal consumption throughout the year, reducing uncertainty through additional analyses was warranted to address potential public concern.

Table 1-1 Summary of Data Gaps and Recommendations

Environmental Medium	***Data Gaps***	***Outcome***
Soil and Dust	- limited residential soil data; - no indoor dust data; and, - no bioaccessibility data.	- collection of soil samples from front and backyards of residential properties; - collection of indoor dust samples from homes and schools; and, - *in vitro* bioaccessibility studies on soil samples.
Air	- current air sampling data does not contain measurements of all metals of concern.	- include additional metals associated with PM_{10} in the analysis of air samples.
Home Garden	- limited data for home gardens in Creighton.	- data are sufficient; no additional sampling is required.
Drinking Water	- limited data representative of drinking water in Creighton - no data for mercury in drinking water in Flin Flon.	- data collected from locations representative of drinking water in Creighton and Flin Flon and analyzed for all metals of concern.
Fish and Sediment	- lack of current data for all metals in edible tissues of fish from lakes likely used for recreational activities.	- additional fish samples were collected and analyzed for all metals of concern in muscle tissue.
Surface Water	- lack of current data for all metals in surface water from lakes likely used for recreational activities.	- additional surface water samples were collected and analyzed for all metals of concern.
Blueberries	- limited data for metals other than lead and mercury.	- blueberry samples collected and analyzed for all metals of concern.

1.7.2 Phase 2 – Problem Formulation

The Problem Formulation Phase of the HHRA process was an information gathering and interpretation stage that planned and focused the study on critical areas of concern for the area being evaluated. The 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 provided information into the physical layout and characteristics of the study area, possible exposure pathways, potential human receptors, COC, and other specific areas or issues of concern to be addressed.

The key tasks requiring evaluation within the problem formulation step included 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 COC - identification of the COC based on site environmental monitoring data;

- Receptor Characterization - identification of "receptors of concern", which in this study included 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 and Scenarios – consideration of various factors that influence the means by which receptors come into contact with COC 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 formed the exposure scenarios which are the basis of the approach taken in the risk assessment. This defined the scope of the HHRA and ensured concerns of all stakeholders were 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. Stakeholder consultation occurred throughout the HHRA process through regular communication among the Technical Advisory Committee (TAC) and the Community Advisory Committee (CAC) members.

1.7.3 Phase 3 – Detailed HHRA

Once all identified data gaps were addressed, the detailed HHRA was conducted, employing a deterministic exposure analysis approach to characterize the exposure, predicted risks, and overall uncertainty inherent within the assessment methodology and results. A detailed discussion of exposure assessment techniques is provided in the HHRA Methodology (see Chapter 4). The following are some of the major items that were incorporated into the detailed HHRA:

- A quantitative exposure analysis that incorporated data gathered during earlier phases of the assessment;
- A multi-pathway risk assessment model, based on published or peer reviewed literature. The model provided results for all COC, receptors and scenarios evaluated;
- A comprehensive toxicological profile for each COC;
- The selection of toxicological criteria (*i.e.*, toxicity reference values or exposure limits);
- The use of exposure and hazard data to characterize potential health risks, under all plausible exposure scenarios, for all receptors and all COC;
- An evaluation of the contribution to risk from each pathway and the cumulative risk from all pathways;
- A quantitative uncertainty and sensitivity analysis to identify those assumptions and exposure pathways which significantly contributed to the overall uncertainty inherent within the predicted risk estimates;

- Development of area-specific, health-based, risk management objectives, when required. These objectives considered ongoing emissions, historical releases and impacts, fate and transport from sources to potentially impacted areas, natural levels in the Flin Flon area environment, and other sources of background exposure (*i.e.*, food); and,
- Consultation with key stakeholders (*e.g.*, Technical Advisory Committee, Community Advisory Committee, and the general public) throughout the entire detailed HHRA process.

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