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

EXECUTIVE SUMMARY

A human health risk assessment (HHRA) was conducted for Hudson Bay Mining and Smelting Co., Limited (HBMS) by Intrinsik Environmental Sciences Inc. (Intrinsik) to address the potential human health risks associated with exposure to smelter-related chemicals (metals and non-metallic elements) 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 Ministry of Environment and Ministry of 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 comments from members of the public, and to demonstrate how HBMS uses that input in the decision making process.

The HHRA was initiated in response to the outcome of a Manitoba Conservation soils study which indicated several chemicals associated with past or present atmospheric emissions of the HBMS complex were at concentrations in excess of those from a selected reference location and Canadian Council of Ministers of the Environment (CCME) soil guidelines protective of human health. The primary objectives of the HHRA were as follows:

> **Objective 1:** To assess risks to human receptors residing in Flin Flon, Manitoba and Creighton, Saskatchewan as a result of exposure to chemicals 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.

This area-wide risk assessment provides an evaluation of current metal exposures, and projected estimated risk levels into the future (*i.e.*, lifetime exposures) based on current chemical concentrations. The HHRA did not evaluate risks related to historical metal exposures, and was not intended or designed to consider the impacts of occupational exposures on the overall health of community members. This report addresses the assessment of health risks and provides recommendations for interim risk management measures and further study to lessen uncertainties and inform the risk management decision making process.

Human Health Risk Assessment Methods

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, soil, sediment, surface water, groundwater, food and biota, *etc*.), under existing or predicted exposure conditions. Calculations of the potential risk (*i.e.,* the chance or likelihood that a particular event will occur) that a given population will experience adverse health effects from exposure to COC are based on mathematical models.

Although risk predictions are typically based on real environmental data, the risk predictions are theoretical because they are calculated using models and assumptions about the population and their exposure to COC.

It is acknowledged that the various uncertainties associated with the HHRA process have the potential to influence estimates of exposure and risk. The methods and assumptions used in this HHRA were designed to be conservative (*i.e.,* health protective), and have a built-in tendency to overestimate, rather than underestimate, potential health risks.

The HHRA was conducted in general accordance with regulatory guidance provided by Health Canada, the U.S. EPA, the Ontario Ministry of the Environment, and the CCME. 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 limited guidance available governing area-wide risk assessment in Canada.

A three-phased approach was applied to the HHRA to ensure it proceeded in a logical and sequential manner, and allowed for unresolved issues or major uncertainties to be addressed as they were identified. The process consisted of a Literature Review, Data Gap Analysis and Supplemental Sampling phase, a Problem Formulation phase, and finally, the detailed HHRA.

Phase One: Literature Review, Data Gap Analysis and Supplemental Sampling

Collection of the necessary data and review of all available primary scientific literature, reports prepared and data collected by government agencies, and information provided by HBMS, was conducted. Information gathered was used to determine what additional sampling and analyses were needed to adequately assess exposure and risk to people in the affected areas. Data collection was initiated accordingly, and included supplemental sampling of soil, indoor dust, air, drinking water, fish, sediment and surface water, wild berries, bioaccessibility testing, and a local food survey of Flin Flon and Creighton area residents.

Phase Two: Problem Formulation

The problem formulation phase, conducted to define the nature and scope of the HHRA, consisted of 4 key tasks: site characterization, identification of COC, receptor characterization, and identification of exposure pathways and scenarios.

Four separate communities of interest (COI) were identified within the Flin Flon-Creighton area, including: East Flin Flon (designated as the area east and northeast of Ross Lake), West Flin Flon (designated as the area west of Ross Lake), Channing, and Creighton.

Screening and subsequent selection of chemicals for evaluation in the HHRA considered all soil contaminant measurements from the study area, collected as part of the 2006 Manitoba Conservation surface soils study and a supplemental residential soil sampling program conducted in 2007. Of a total of 24 chemicals considered, six were identified as COC and retained for detailed quantitative evaluation in the HHRA: arsenic, cadmium, copper, lead, mercury, and selenium. These chemicals were those found to be elevated across a significant portion of the study area, in excess of human health-based soil criteria, strongly inter-correlated, and known to be past or present constituents of the HBMS smelter emissions.

Selection and characterization of receptors (*i.e.*, a hypothetical person who may reside, spend leisure time and/or work in the Flin Flon/Creighton area and is, or could potentially be, exposed to the COC) considered those individuals with the greatest potential for exposure to COC, and those that have the greatest sensitivity or potential for developing adverse effects from these exposures. Five age classes as per Health Canada (2006) were selected (*i.e*., infant, toddler, child, teen, and adult), as well as a lifetime composite receptor for the assessment of lifetime cancer risks from carcinogenic COC. Receptor characteristics reflective of a central tendency estimate were selected for use in the HHRA.

Multiple exposure pathways, or the means by which a receptor comes into contact with a chemical in an environmental medium, were considered, including:

- ingestion exposure pathways (*i.e.*, exposure from ingestion of COC in outdoor soil and indoor dust, home garden vegetables, typical market basket items, local wild blueberries, local fish and wild game, drinking water derived from Flin Flon and Creighton area water resources, snow, and surface water and sediment ingestion while swimming);
- inhalation exposure pathways (*i.e.,* exposure from direct inhalation of COC in outdoor air and indoor air); and,
- dermal exposure pathways (*i.e.*, exposure from dermal contact with COC in outdoor soil, indoor dust, and surface water).

Three main exposure scenarios were developed based on the likelihood that particular activities and behaviour patterns would be applicable to certain groups or subpopulations. Exposure scenarios included a residential scenario for each of the COI (*i.e.*, East Flin Flon, West Flin Flon, Channing and Creighton), a residential typical background scenario (included to estimate exposure of residents of a typical northern Manitoba/Saskatchewan community that has not been impacted by any point source of emissions), and an outdoor commercial/industrial worker scenario. A supplemental recreational scenario was also included.

Phase Three: Detailed Human Health Risk Assessment

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. Separate assessments were completed for short-term (acute) and long-term (chronic) durations because the health outcomes produced by some COC depend on the duration of exposure.

Exposure Assessment

The rate of exposure (*i.e.*, the quantity of chemical and the rate at which that quantity is received) of receptors to the COC *via* the identified exposure scenarios and pathways was predicted using community-specific exposure point concentrations (EPCs) and a series of conservative assumptions. EPCs, (*i.e*., the concentration of a chemical in any environmental medium to which a receptor could reasonably be expected to be exposed over an extended period of time) developed for each COC in environmental media of concern, were typically defined as the 95% upper confidence limit of the mean (UCLM).

The underlying assumption used when developing the chronic residential exposure scenarios was that individuals would move randomly within each community and, therefore, over time, come into contact with the 95% UCLM concentration of COC within a given community (or exposure unit). Use of the 95% UCLM concentrations over average concentrations ensure that the HHRA accounted for receptors who may be more highly exposed to the COC than the general population.

An integrated multi-pathway risk assessment model was developed to calculate potential exposures to all COC, expressed as the amount of chemical taken in per body weight per unit time (*e.g.*, µg chemical/kg body weight/day). In the calculation of lead exposures, the Integrated Exposure, Uptake, and Biokinetic (IEUBK) model developed by the U.S. EPA was also used to predict distributions of blood lead levels (BLLs) in children and the proportion of populations that may have BLLs in excess of levels of concern.

In the exposure assessment of carcinogenic COC, it was conservatively assumed that receptors would spend their entire lifetime living in the COI. Therefore, to assess the incremental lifetime cancer risk (ILCR), the Lifetime Average Daily Dose (LADD) was calculated based on the predicted exposure for each individual age class (*i.e*., infant, toddler, child, teen, adult) weighted according to the age class duration (referred to as a "composite receptor").

Hazard Assessment

As part of the hazard (or toxicity) assessment, a comprehensive toxicological profile was developed for each COC, detailing mechanisms of action, relevant toxic endpoints, and receptor- and route-specific toxicological criteria. Based on consideration of this data, toxicological criteria (*i.e*., toxicity reference values or exposure limits) against which exposures were compared in the estimation of potential health risks, were selected. Acute and chronic exposure limits were adopted for all COC based on threshold response effects (*i.e*., non-carcinogenic effects). Chronic exposure limits based on carcinogenic (non-threshold) effects were also selected, where appropriate (*i.e.*, for consideration of cadmium *via* inhalation and arsenic *via* inhalation, ingestion, and dermal contact).

Risk Characterization

Potential risk for all receptors and COC was characterized through a comparison of the estimated or predicted exposures from all pathways (from the Exposure Assessment) with the identified toxicity reference values (from the Hazard Assessment) under all plausible exposure scenarios. The contribution to risk from each pathway, and the cumulative risk from all pathways, were both evaluated.

For non-carcinogenic COC, risk levels were expressed as Hazard Quotients (HQs) and were calculated by dividing the predicted exposure level by the exposure limit. Using this method, there is a potential for an elevated level of risk if the estimated exposures received by the receptor exceed the regulatory exposure limit (*i.e.,* HQ >1.0). Predicted health risks are considered acceptable when the estimated exposures are less than or equal to the regulatory exposure limit (*i.e.,* HQ ≤1.0). Added assurance of protection is provided by the high degree of conservatism (protection) incorporated in the derivation of the exposure limit.

For chemicals with non-threshold-type dose responses (*i.e.,* carcinogens), the comparison is referred to as the Incremental Lifetime Cancer Risk Level (ILCR). The ILCR represents an upper bound estimate of the additional incidence of cancer (*i.e.,* occurrence of cancer that would not be expected in the absence of the exposure) in a population of people exposed every day over their entire lifetime. The ILCR is calculated by multiplying the predicted exposure by the slope factor or unit risk value. The ILCR is expressed as the prediction that one person per ***n*** people would develop cancer, where the magnitude of ***n*** reflects the risks to that population.

In the case of carcinogens, the acceptable risk level in Manitoba is considered to be an incremental increase in cancer risk of one-in-one hundred thousand (*i.e.*, one additional cancer per one hundred thousand people).

The current community intervention level established by Health Canada for blood lead is 10 µg/dL, but there is a large volume of literature which suggests that health effects in children occur at concentrations lower than this level. The 10 µg/dL value is currently under review by Health Canada, and it is anticipated that Health Canada will reduce the intervention level in the near future (and hence, the Toxicity Reference Value (TRV) would also be lowered).

The residential typical background exposure scenario was included in the HHRA to provide additional information in the evaluation and interpretation of HQs and ILCRs. This allowed for comparison between the HQs/ILCRs predicted from a typical background exposure scenario and the risk estimates calculated for the COI.

In addition to predicting risks using the community-based EPCs, soil provisional trigger concentrations (PTCs), defined as the average COC soil concentration within a given exposure unit (*i.e.,* a residential property) that corresponds to an acceptable level of risk, were derived for each COC to be protective of residential receptors. PTCs can be used to determine on a property-by-property basis, which properties contain concentrations that have the potential to cause unacceptable risks. These PTCs do not represent soil remediation objectives but rather triggers to determine whether additional studies such as biomonitoring are warranted to reduce uncertainty in the assessment of exposure and risk. The need for final remediation objectives or risk management measures will be determined based on the outcome of these additional studies.

As mentioned, the methods and assumptions used in this HHRA are designed to be conservative (*i.e.,* health protective), and have a built-in tendency to overestimate, rather than underestimate, potential health risks. Thus, risk estimates that are within an order of magnitude of the acceptable risk benchmarks may reflect overestimation through the use of overly conservative assumptions and parameters. In these cases, interpretation of the risk estimates may indicate that given the conservatism of the assessment, no adverse health effects would be expected despite the exceedance of the acceptable risk level or, that further assessment (*i.e.,* progression to a more detailed and specific risk assessment that could involve further data collection or probabilistic exposure analysis), or mitigative measures are warranted.

Results and Recommendations

Acute Exposure Scenarios

Acute inhalation exposures are short-term and transient in nature, typically occurring as a result of a unique or extreme weather condition or facility anomaly resulting in short-term deviations from normal concentrations. Acute inhalation risk estimates were based on exposure periods that last from a few minutes to a few days and were characterized through consideration of 24-hour maximum air concentrations.

Minor acute inhalation risks were predicted for arsenic and lead in the West Flin Flon area only. For a one-year period from 2007 to 2008, 9 of 210 air samples collected in West Flin Flon were in excess of the TRV for arsenic, and 2 were in excess of the TRV for lead. The highest HQs for arsenic (2.5) and lead (1.2) were in excess of the acceptable level (1.0), however, given the inherent conservatism associated with the acute TRVs, these exceedances are considered to be minor. The results of this evaluation indicated that some people may experience short-term and reversible health effects at intermittent times during facility operations in the West Flin Flon area. These occurrences are somewhat rare, the magnitude of exceedances are less than an order of magnitude, and the margins of safety inherent in the acute TRVs are large, indicating that the occurrence of acute health effects associated with inhalation of air is unlikely.

For soil and snow pathways, acute exposure estimates were based on short-term transient exposures related to extreme activities and upper bound levels of COC in soil and/or snow. Children were assumed to ingest larger than normal quantities of soil on rare occasions, and to consume snow in relatively large quantities over a short time-frame.

For acute soil ingestion, marginal exceedances of the acceptable HQ (1.0) were noted for arsenic in West Flin Flon (HQ of 1.2) and Creighton (HQ of 1.4), and for mercury in West Flin Flon (HQ of 3.4). The results of this evaluation indicated that some people may experience short-term and reversible health effects such as irritation and gastrointestinal upset. However, the likelihood is rare, the magnitude of exceedances are small and the margins of safety inherent in the acute TRVs are large, indicating that the occurrence of acute health effects from acute soil ingestion is unlikely.

No acute HQ exceedances were noted for the snow pathway indicating that infrequent consumption of snow within the Flin Flon-Creighton area is not anticipated to result in adverse health effects.

Chronic Residential Exposure Scenarios

Long-term or chronic risks (>1 year to a lifetime) were characterized by comparing predicted exposures from all pathways with the TRVs. Chronic health risks were estimated based on the assumption that an individual is continuously exposed to COC in all media. The chronic risk estimates were based on an exposure duration of one year to an assumed lifespan of 80 years.

Exceedance of the acceptable non-cancer and cancer risk levels is used as a general indicator of unacceptable or elevated risk; however, elevated risk may occur to varying degrees. Recognized experts in the field of risk communication have suggested the use of qualitative terminology to express the varying levels of numerical risk (Calman, 1996[1]; Paling, 2003[2]). A carcinogenic risk level of less than 1-in-1 million is considered *negligible*; between 1-in-1 million and 1-in-100,000 is considered *minimal*, and for the purposes of this risk assessment, acceptable; between 1-in-100,000 and 1-in-10,000 is considered *very low*; between 1-in-10,000 and 1-in -1,000 is considered *low*; between 1-in-1,000 and 1-in-100 is considered *moderate*; and greater than 1-in-100 is considered *high* (Calman, 1996; Paling, 2003). These definitions may be useful in understanding the relative risks expressed below.

An acceptable level of risk was predicted under the assessment of non-carcinogenic risks for cadmium, copper, and selenium throughout the communities of interest as a result of exposure to these COC in soil, local foods, drinking water, and other environmental media. The predicted HQs for these COC were below the acceptable level of 1.0 for all receptors in each community. In addition, comparison of the PTCs derived for these COC to all concentrations measured on residential properties throughout the Flin Flon-Creighton area indicated that despite a high degree of variability in soil concentrations, concentrations of these COC in residential soils are not anticipated to result in unacceptable risks. Although the multi-media exposure assessment

[1] Calman, K.C. 1996. Cancer: science and society and the communication of risk. BMJ 1996:313:799-802.
[2] Paling, J. 2003. Strategies to help patients understand risk. BMJ (327):745-748.

indicated that non-cancer risks for cadmium are acceptable, ILCRs for inhalation of cadmium in ambient air were above the acceptable risk level of $1.0x10^{-5}$ (or 1-in-100,000) in each of the four COI ($4.5x10^{-5}$ in Creighton to $6.9x10^{-4}$ in West Flin Flon). Carcinogenic health risks associated with the inhalation of cadmium were considered very low to low, however, consideration should be given to future reductions in smelter-related emissions which would have a direct and immediate effect on reducing inhalation-related exposure and risks.

Given that concentrations of cadmium, copper, and selenium in soil in the Flin Flon-Creighton area are not anticipated to result in unacceptable risks, soil remediation objectives were not derived for these COC. Current concentrations can safely remain in place without the need for measures to prevent or reduce exposure.

The assessment of risk from exposure to lead indicated that the primary sources of lead exposure were through ingestion of outdoor soil and indoor dust, and the consumption of market basket foods. Although the predicted HQs (0.10 to 0.59) were below the acceptable level (1.0), and geometric mean blood lead concentrations (3.8 to 4.5 µg/dL) were within an acceptable range based on the overall community assessment, there are a number of individual properties throughout Flin Flon and Creighton that contain concentrations in excess of the PTC. This indicates that a number of residential properties contain concentrations of lead that may warrant further assessment of childhood lead exposure through the collection and analysis of blood samples. The need for remediation objectives or risk management measures can be evaluated following the outcome of a childhood lead exposure study.

The assessment of risk from exposure to mercury was completed for both inorganic mercury and methyl mercury. Results of the community-based assessment indicated that the HQ for inorganic mercury for the toddler living in West Flin Flon (1.8) was in excess of 1.0. The primary source of exposure to inorganic mercury in West Flin Flon was ingestion of outdoor soil. Comparison of the PTC derived for inorganic mercury to concentrations measured on individual properties indicated that a number of residential properties in West Flin Flon contained concentrations in excess of this value. This indicates that a number of residential properties contain concentrations of mercury that may warrant further assessment of exposure through the collection and analysis of urine samples. The need for remediation objectives or risk management measures can be evaluated following the outcome of a childhood inorganic mercury exposure study. Concentrations of mercury on all properties sampled in East Flin Flon, Creighton, and Channing were below the PTC.

Exposure and risk associated with methyl mercury are primarily attributed to the consumption of local fish. Ongoing fish collection and analysis for methyl mercury is recommended to assess the need for future fish consumption advisories for this area, particularly for sensitive receptors.

Predicted HQs for Flin Flon-Creighton residents exposed to arsenic ranged from 0.49 to 1.9, with higher values associated with exposure in young children. HQ estimates for the Typical Background scenario (0.43 to 1.3) were similar to those predicted for residents in the COI. This is a result of the significant contribution of market basket foods to total exposure and the similar concentrations of arsenic in drinking water in the Flin Flon-Creighton area relative to background drinking water concentrations. The difference in exposure to inorganic arsenic between residents of the COI and the Typical Background scenario can be attributed primarily to incidental soil/dust ingestion and inhalation of ambient air. This difference in exposure is a result of the elevated concentrations of arsenic in soil and air in the Flin Flon-Creighton area relative to the Typical Background concentrations.

ILCRs for arsenic were in excess of the acceptable level of $1.0x10^{-5}$, ranging from $3.0x10^{-4}$ to $5.0x10^{-4}$. The most significant source of cancer risk for East and West Flin Flon and Channing is the inhalation of arsenic in air. Since concentrations of arsenic in ambient air in Creighton are lower than in other COIs, this pathway is less significant in Creighton. Although the consumption of drinking water also significantly contributed to the overall cancer risk levels, this does not represent an incremental increase in cancer risks experienced under the Typical Background scenario *via* this pathway because concentrations of arsenic in drinking water in Flin Flon and Creighton are similar to those measured in drinking water throughout Manitoba and Saskatchewan. Comparison of the PTC derived for arsenic to concentrations measured on individual properties indicated that a number of residential properties in West Flin Flon and Creighton contained concentrations in excess of this value. This indicates that a number of residential properties contain concentrations of arsenic that may warrant further assessment of exposure through the collection and analysis of urine samples. The need for remediation objectives or risk management measures can be evaluated following the outcome of a childhood arsenic exposure study. In addition, consideration should be given to future reductions in smelter-related emissions which would have a direct and immediate effect on reducing inhalation-related exposure and risks.

Outdoor Worker Scenario

Under the outdoor worker scenario, it was assumed that workers would spend a significant amount of time outdoors exposed to soils on non-residential properties. Overall, no unacceptable cancer or non-cancer risks are anticipated for individuals working (but not residing) in the Flin Flon area. Workers that live in the Flin Flon area would be subject to similar risk levels estimated under the residential scenarios.

Recreational Scenario

Under a supplemental recreational assessment, it was assumed that receptors may spend a significant portion of the summer months swimming in local lakes. Exposure to COC was assumed to occur *via* incidental ingestion of surface water and sediment, as well as dermal contact of surface water with all skin.

No unacceptable cancer or non-cancer risks were estimated for receptors swimming in lakes in the Flin Flon-Creighton area throughout the summer months. Exposure and risks associated with these pathways are considered to be very minor and are not anticipated to result in the occurrence of adverse health effects.

Overall Recommendations

The results of the HHRA indicate that concentrations of cadmium and arsenic measured in ambient outdoor air in the Flin Flon area may result in a very low to low increase in the risk of developing lung cancer, however because of the population size of the Flin Flon area, a detectable increase is not expected. Future reductions in smelter-related emissions containing arsenic and cadmium would have a direct and immediate effect on reducing inhalation-related exposure and risks. Given that the HBMS smelter ceased operations in mid-June 2010, concentrations of arsenic and cadmium in ambient air are anticipated to be reduced to levels below those that are associated with an increased risk of developing lung cancer. It is recommended that Provincial and HBMS air monitoring programs are continued in the future to ensure that concentrations meet regulated air standards.

Concentrations of arsenic, lead, and inorganic mercury in soils on a number of residential properties in the Flin Flon area are in excess of PTCs derived to be protective of health. It is recommended that to reduce uncertainty in the assessment of exposure and risk, a comprehensive biomonitoring study is completed in which blood and urine samples are collected from children living in the Flin Flon area. Analyses of arsenic and inorganic mercury in urine samples, and lead in blood, will provide measurements of actual exposure of children to these chemicals and allow for a more accurate assessment of potential risks.

The HHRA and biomonitoring study will inform the risk management decision making process by providing information on the actual levels of exposure and the pathways of potential concern. This allows for risk managers to focus on those environmental media that may be contributing most significantly to total exposure and those that may be most effectively mitigated.