SCIENCE INTEGRITY KNOWLEDGE

LITERATURE REVIEW AND DATA GAP ANALYSIS

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

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1.0 INTRODUCITON

Hudson Bay Mining and Smelting Co., Limited (HBMS) has operated a base metal smelting complex in the city of Flin Flon, Manitoba since 1930. This facility produces copper, cadmium, and zinc metal (Henderson et al., 1998). 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 in the early 90's reduced emissions by approximately 90% from pre-1974 levels (McMartin *et al*., 1999).

As a result of the 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 Flin Flon and Creighton. As part of the initial stages of the HHRA, Intrinsik has completed 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 will be used to determine if additional sampling and analysis is required to adequately assess exposure and risk to people in the affected areas. It is intended that distribution of this report to stakeholders representing the public and private sectors as well as all levels of government will assist in the identification of additional information to fill any data gaps identified.

This report provides a summary of the literature reviewed as well as a data gap analysis for information relevant to the HHRA. Sections 2.0 through 8.0 describe information gathered describing metal content in soil, ambient air, home garden produce, drinking water, fish and sediment, surface water, and local blueberries, respectively. Appendix A provides individual summaries of the resources reviewed.

This report summarizes all literature and data obtained prior to September 2007. Relevant information obtained following the completion of this report will be incorporated into the HHRA.

SOIL AND DUST DATA

2.1 Summary of Review

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. 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.

A large regional geochemical mapping project conducted by the Geological Survey of Canada and Manitoba Energy and Mines studied soils in Flin Flon, central Manitoba, and Saskatchewan and has served as the basis for several additional soil studies (Henderson, 1995; McMartin *et al*., 1996). Humus and till were sampled at over 1,600 sites within a 200 km radius of the HBMS smelter in Flin Flon. Samples were taken at an average spacing of 4 km, with a total of 1,817 samples of till and 1,639 samples of humus collected (McMartin *et al*., 1999). Concentrations of metals were reported to vary significantly depending on the depth at which samples were collected. Several studies have found that concentrations are significantly higher in the upper soil layer composed of a large amount of organic material, commonly referred to as humus, relative to the underlying till layer (Henderson and McMartin, 1995; Henderson *et al*., 1998; McMartin *et al*., 1999; and, Manitoba Conservation, 2003).

Chemical content in humus and till can be influenced by atmospheric releases of gases and particulates from the smelter as well as the deposition of dusts originating from tailings, exposed ore residue dumps, and ore and concentrate disturbed during transportation (Franzin, 1984). Although deposition is a significant source to concentrations in humus, metals that naturally occur in the environment, such as lead and mercury, also tend to concentrate in humus as a result of long-term upward translocation by plant roots and accumulation through the decomposition of plant materials (Stevenson, 1994). Acknowledging that concentrations in humus are a reflection of mixing with the mineral matter and biogeochemical cycling (Steiness and Njastad, 1993), in the Flin Flon region the primary factor is believed to be the contribution from the HBMS complex (McMartin *et al*., 1999). Concentrations of metals in this layer show a strong negative correlation with distance, decreasing with increasing distance from the smelter. Zinc was found up to 94 times the concentration found in regional background samples at a distance of 10 km and reduced to 1.6 times regional background levels at a distance of 80 km (Henderson *et al*., 1998). Concentrations of mercury reached a maximum of 500 times the regional background concentration at a distance of <5 km and reduced to 1.5 times at a distance of 40 km. Henderson and McMartin (1995) found that concentrations of mercury in humus were higher than those measured in till, with median concentrations of 266 ppb and 50 ppb in humus and till, respectively. Concentrations of mercury in humus were as high as 250 times the estimated background concentration of 400 ppb, whereas concentrations in till were only as high as 7 times the background concentration (60 ppb). Concentrations in humus decreased rapidly with distance from the smelter and generally returned to background levels at a distance of 35 km (Henderson and McMartin, 1995).

While the concentrations of metals in humus in the Flin Flon area are influenced by the smelter, concentrations in till can be heavily influenced by the composition and nature of the underlying bedrock and are modified by glacial erosion, transport, and deposition (McMartin *et al*., 1996). Generally, concentrations of all smelter-related metals are higher in humus than in the underlying till. Concentrations in till are often not directly related to distance from the smelter and are generally less variable than concentrations in humus. Concentrations of mercury in till were found to be relatively constant regardless of distance (Henderson and McMartin, 1995). Overall, contamination of smelter-related metals is generally restricted to the organic surface horizon (humus) and concentrations are poorly correlated with concentrations in the underlying till. However, in close proximity to the smelter (<10 km), migration through the soil profile is significant and elevated concentrations are found to a minimum depth of 45 cm.

While the primary literature provides insight and interpretation of patterns of soil contamination in the Flin Flon area, four separate studies completed by Manitoba Conservation offer the largest and most complete sets of raw data to be utilized for the HHRA. In 2000, as part of a study in which concentrations of several metals were measured in blueberries collected from a number of locations in the Flin Flon area, soil concentrations from the sampling locations were also measured. A report is not available to discuss the sampling protocol or a summary of the results, however, a database of the results of the soils analysis was provided. Three soil samples, at depths ranging from 1.5 to 7 cm bgs (below ground surface), were taken from each of 13 sites; 11 from the Flin Flon area, and two others likely representing regional background concentrations. Easting and northing coordinates are provided for each location (Manitoba Conservation, 2000). While some of the sampling locations may not be representative of areas in which people will spend prolonged durations, this data set can be used in combination with the 2006 Soils Study to support the selection of the chemicals of concern (COCs) to be retained for further evaluation in the HHRA. In addition, should it be required that concentrations in wild game or local berries or other edible plants and fruits be predicted based on environmental concentrations, these data may represent the most appropriate basis for these calculations.

During the summers of 1998, 1999, and 2003, Manitoba Conservation conducted a soils study for forest sites in the Flin Flon area (Manitoba Conservation, 2003). A total of 16 samples were taken at each of seven locations in Flin Flon and one reference location, at depths ranging from 0 to 15 cm bgs. The first round of sampling at these locations occurred during the summers of 1998 and 1999. These locations were re-sampled during the summer of 2003. As found in Henderson and McMartin (1995) and McMartin *et al*. (1999), the highest measured concentrations of smelter-related metals were generally found in the upper 0 to 6 cm within the organic layer of soil. As with the results of the blueberry study, sampling locations from this study may not be representative of areas in which people will spend prolonged durations, however, concentrations may be helpful to characterize levels in wild game or other food items.

In 2002, Manitoba Conservation designed and completed a home garden sampling program to address public concerns raised in response to discrepancies reported in the home garden surveys completed by Pip (1991) and HBMS (1994a). Nine home gardens from the Flin Flon area, located at varying distances and directions from the HBMS complex, were selected to characterize the potential influence of smelter-related emissions (Manitoba Conservation, 2006). In addition, a garden located in the community of Cranberry Portage was selected to be representative of an area that is minimally impacted by smelter emissions. A garden in the town of The Pas was selected to represent a non-impacted control site. In addition to home garden produce data, this report provides a significant database of concentrations of metals in soils on residential properties. Manitoba Conservation has provided detailed spreadsheets of all soil data collected as part of this study. Three replicate soil samples were collected from each of eleven garden plots. Samples were collected from a depth of 10 cm. Although samples taken from this depth may not be, representative of soils to which people would be exposed to for prolonged durations, this data set can be used in combination with the 2006 Soils Study and other Manitoba Conservation studies to support the selection of the COCs to be retained for further evaluation in the HHRA.

Finally, the primary source of soil data for the HHRA is currently the surface soil sampling program conducted by Manitoba Conservation in August, 2006 which involved the collection of soil from 93 sites in Flin Flon and 13 sites in Creighton (Manitoba Conservation, 2007). 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 the following twelve chemicals were found to be elevated relative to concentrations measured in the Cranberry Portage reference area:

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

In addition to the finding that concentrations of these compounds were elevated across much of the study area, they were also strongly inter-correlated and are known to be past or present constituents of the HBMS smelter emissions. When compared to the CCME soil quality guidelines and interim remediation criteria for soils under a residential or parkland scenario, concentrations of arsenic, cadmium, copper, lead, mercury, selenium, and thallium all exceeded their respective guidelines. Although concentrations of zinc exceeded the CCME guideline, this guideline is protective of environmental health and does not contain a human health component. Concentrations of antimony, molybdenum, silver and sulphur did not exceed their corresponding interim remediation criterion.

It is anticipated that the results of this report will form the basis of the Problem Formulation for the HHRA. Although other studies which involved the collection and analysis of soils will be considered, this report provides the most complete database and the most relevant sampling depths and locations to the HHRA. As discussed previously, to ensure that the selection of COCs for the HHRA does not exclude any chemicals which may be found at concentrations in excess of the relevant screening criteria, data from all four Manitoba Reports may be considered. For comparative purposes, the maximum concentrations of the anticipated COCs were identified from each of the Manitoba Conservation studies and compared to the CCME Human Health Guideline for residential/parkland properties (Table 2-1).

Table 2-1 Comparison of Maximum Soil Concentrations Measured During Four Separate Manitoba Conservation Studies (µg/g)

Metal	***2006 Soils Study[b]***	***2000 Blueberry Study***	***2002 Home Garden Study***	***1998/1999/2003 Forest Soils Study***	***CCME HH Guideline***
Antimony	11.2	-	<10	8.6	20[a]
Arsenic	**407**	**210**	**50.4**	**210**	12
Cadmium	**70.9**	**125**	11	**85**	14
Copper	**5103**	**5060**	747	**3010**	1100
Lead	**1446.7**	**2500**	**474**	**1740**	140
Mercury	**653**	**44.3**	**25.9**	**30.6**	6.6
Molybdenum	8	<10	<4	9.8	10[a]
Selenium	**177.2**	-	6.3	25.2	28
Silver	7.5	-	1.8	3.2	20[a]
Thallium	**1.2**	**<10**	0.3	1.3	1.0
Zinc	11150	24700	3120	15300	NA

[a] Value represents the CCME interim remediation criterion.
[b]Value represents the average of three samples taken per location
Values in Bold are in excess of the CCME Human Health Guideline for residential and parkland properties.

Although the maximum concentrations for some chemicals were higher in studies other than those reported in the 2006 soils study, inclusion of data from these studies would not likely result in the retention of additional COCs for the HHRA. This comparison lends support to the use of the 2006 soils study as the primary resource for the preparation of the Problem Formulation and Terms of Reference for the HHRA.

2.2 Data Gap Analysis

A potential area of significant uncertainty is the absence of soil samples taken from the front and backyards of residential properties. Although the Manitoba Conservation soils study has effectively characterized concentrations in 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 COCs 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.

While an accurate assessment of the concentration of a chemical in soil and dust is an important component of the HHRA, so to is the assessment of the chemical form of a COC in soil and its bioavailability. Analyses of chemical forms in previous studies have indicated that 50 to 60% of zinc and 20 to 35% of copper in upper organic layers of forest floors were in bioavailable forms (Hogan and Wotton, 1984). Henderson *et al*. (1998) used a sequential extraction analysis to show that copper, cadmium, lead, and zinc are found in a highly leachable (labile) form in the soluble organic phase of humus (humic and fulvic complexes). In contrast, arsenic and mercury were found to be in less mobile nonlabile phases (humin and mineral matter).

The ingestion of soils is often considered to be the major route of exposure for heavy metals in humans. To effectively assess the amount of soil metals to which humans are exposed, the determination of bioavailability becomes an invaluable tool in risk assessment. Present recommendations for oral bioavailability assessment of soil contaminants can be divided into four fundamental processes: i) the oral intake of organic matrix including metals; ii) bioaccessibility; iii) intestinal absorption; and, iv) metabolism in the liver/intestines. Out of these processes that construct the basis of bioavailability, bioaccessibility testing is a key component. The inclusion of bioaccessibility testing as part of the assessment process allows for a more realistic estimate of the systemic exposure to metals from soil and dust ingestion than using generic assumptions such as those employed to derive soil guideline values. Oral bioaccessibility can be defined as the fraction of a substance that is released from the soil or dust matrix during digestion, thus making it soluble and available for absorption through the gastrointestinal tract. The bioaccessible fraction is the fraction of the substance of interest that is dissolved from soil into the intestinal fluids, and represents the maximum fraction available for intestinal absorption. While bioaccessibility testing may be a valuable addition to risk assessment practices, it is an evolving science and several uncertainties remain. Oral bioaccessibility results have been shown to vary considerably within and between contaminated sites. Therefore, it is prudent to only apply bioaccessibility data on a site-specific basis.

2.0 AIR DATA

3.1 Summary of Review

HBMS currently operates air sampling stations at Ruth Betts School in Flin Flon and at Creighton School in Creighton. HBMS historically operated an additional monitor at the Sewage Treatment Plant in Flin Flon but it appears that monitoring at this location was discontinued in 2002. HBMS reports data for TSP, PM_{10}, and $PM_{2.5}$ and metals associated with each of these fractions on a daily 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, the HBMS-operated samplers will likely provide the most useful data. 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 (Table 3-1).

Table 3-1 Annual Average Metal Concentrations Associated with PM_{10} in Ambient Air (µg/m^3)

Location	*Lead*	*Copper*	*Cadmium*	*Zinc*	*Arsenic*
Ruth Betts School					
2002	0.15	0.35	0.02	0.56	0.02
2003	0.16	0.33	0.02	0.78	0.04
2004	0.03	0.13	0.00	0.76	0.01
2005	0.07	0.18	0.01	0.37	0.02
2006	0.06	0.13	0.02	0.13	0.02
Creighton School[a]					
2003	0.42	0.15	0.04	0.24	0.01
2004	0.42	0.13	0.04	0.23	0.01
2005	0.42	0.13	0.06	0.36	0.01
2006	0.17	0.05	0.01	0.09	0.01

[a] Measurements are from the dichotomous air sampler.

Annual average concentrations of lead, copper, and zinc from the Creighton School are notably higher than those reported at Ruth Betts. While this may be an accurate reflection of differences in conditions resulting from wind patterns or the potential influence of the Tailings Management Area located to the north of Creighton, it may also be skewed by differences in air samplers used at these locations. In 2003, when a dichotomous air sampler replaced the previous air sampler located at the Creighton School, the concentrations of metals associated with the PM_{10} component increased significantly. According to HBMS (pers. comm. 2007), the dichotomous sampler uses an 8 cm filter that retains less particulates than the previous sampler, and the sampler located at Ruth Betts, which uses a 10 cm filter. The reported increase in concentrations of certain metals associated with the PM_{10} component may be the result of elevated detection limits that are used to analyze for metals in the smaller samples collected by the dichotomous sampler. As a result, it may not be appropriate to directly compare concentrations collected from the Ruth Betts and Creighton schools.

3.2 Data Gap Analysis

Currently, the air samples collected at Ruth Betts and the Creighton School are only analyzed for five (arsenic, copper, cadmium, lead, and zinc) of the 11 metals reported to be elevated in soils in the Flin Flon area. As a result, based on discussions with Stephen West and Joel Nilsen of HBMS on August 27, 2007, HBMS has agreed to add the remaining six metals (antimony, mercury, molybdenum, selenium, silver, and thallium) to the list of chemicals analyzed for at each location. Since the 8 cm filter used within the dichotomous monitor at the Creighton School would not likely retain enough particulates to allow for analysis of these additional metals (particularly mercury), HBMS has indicated that they will operate an additional 10 cm monitor at this location to collect additional particulates. Sampling will occur every three days.

Based on a comparison of metals associated with TSP at the Provincial Building, Ruth Betts School, and Creighton School, concentrations of arsenic, cadmium, copper, lead, and zinc are all highest at the Provincial Building (Table 3-2). Although HBMS has agreed to test for all 11 metals associated with PM_{10} at the Ruth Betts and Creighton Schools, assuming that the relationship of concentrations in PM_{10} between these locations is similar to the observed relationship in concentrations in TSP, the absence of these data for the Provincial Building may create a significant area of uncertainty for the HHRA.

Table 3-2 Annual Average Metal Concentrations Associated with TSP in Ambient Air (µg/m^3)

Location	*Lead*	*Copper*	*Cadmium*	*Zinc*	*Arsenic*	*Mercury*
Provincial Building						
2002	0.276	0.979	0.045	2.280	0.043	-
2003	0.225	1.042	0.032	1.820	0.054	-
2004	0.109	0.980	0.015	2.457	0.038	-
2005	0.175	0.894	0.022	1.646	0.043	-
2006	0.144	0.940	0.041	2.245	0.049	-
2007[a]	0.263	1.369	0.054	1.343	0.081	-
Ruth Betts School						
2002	0.150	0.688	0.019	0.851	0.037	0.0006
2003	0.136	0.799	0.018	1.193	0.037	0.0008
2004	0.040	0.576	0.006	0.898	0.016	0.0008
2005	0.089	0.764	0.014	0.603	0.023	0.0006
2006	0.059	0.742	0.020	0.287	0.024	0.0005
2007[a]	0.086	0.874	0.025	0.593	0.044	0.0003
Creighton School						
2002	0.167	0.560	0.005	0.773	0.151	-
2003	0.036	0.647	0.004	0.427	0.009	0.0003
2004	0.028	0.495	0.003	0.470	0.006	0.0004
2005	0.039	0.417	0.007	0.334	0.011	0.0004
2006	0.024	0.446	0.005	0.143	0.008	0.0001
2007[a]	0.027	0.415	0.005	0.076	0.009	0.0001

[a] Concentrations are the average for data sampled from January 1 to May 31 2007.
* Note: From January, 1998 to mid-2005, samples from Ruth Betts, Sewage Plant, and Creighton School were only analyzed when wind direction was from the facility.

3.0 HOME GARDEN DATA

4.1 Summary of Review

Three primary studies have measured concentrations of metals in home garden soil and produce. The first was completed by Pip (1991) in which soil and vegetable samples were collected from home gardens at the end of the 1989 growing season at 12 locations that raged in distance from 0.29 to 12.8 km northeast to southwest of the HBMS complex. Concentrations of cadmium, copper, and lead were measured in soil and produce. Overall, a strong intercorrelation was found for all metals in soil and although a significant level of variation was noted for concentrations of metals in produce, when concentrations in all produce were pooled (untransformed data), a significant inverse relationship was noted with distance from the smelter (log transformed data). Leafy tissues had significantly higher concentrations than fruits and below ground tissues. However, concentrations in leafy tissues were not significantly correlated with concentrations in soil. This was attributed largely to aerial deposition and the large surface area to volume ratio of leafy tissues (Pip, 1991).

In 1994, HBMS completed their own home garden survey by collecting soil and vegetable samples from seven gardens in Flin Flon and one in Creighton. In addition, vegetable samples were taken from a local grocery store and submitted for analysis to allow for a comparison to the results of the home garden survey. Consistent with Pip (1991), HBMS found that concentrations of metals in soil and vegetables decreased with increasing distance from the complex and that concentrations in vegetables were positively related to concentrations in soil. As found in the Pip (1991) study, concentrations in leafy vegetables, such as lettuce, cabbage, chard, and beet tops were significantly higher than those observed in other types of vegetables (HBMS, 1994a).

When compared to concentrations in vegetables collected from the local grocery store, HBMS (1994a) found that mean concentrations in carrots and tomatoes from home gardens were similar. However, lettuce from home gardens had concentrations of all metals except lead that were 50% to 75% higher than lettuce from the local grocery store. Concentrations of lead in lettuce from home gardens was approximately 70% lower than lettuce from the local grocery store (HBMS, 1994a).

To address public concerns raised in response to discrepancies reported in the home garden surveys completed by Pip (1991) and HBMS (1994a), Manitoba Conservation designed and completed a home garden sampling program in 2002. Nine home gardens from the Flin Flon area, located at varying distances and directions from the HBMS complex, were selected to characterize the potential influence of smelter-related emissions. In addition, a garden located in the community of Cranberry Portage was selected to be representative of an area that is minimally impacted by smelter emissions. A garden in the town of The Pas was selected to represent a non-impacted control site (Manitoba Conservation, 2006).

Analysis of soil samples indicated that mean concentrations of several metals were significantly higher in Flin Flon gardens relative to the control site garden in The Pas (Manitoba Conservation, 2006). Concentrations of arsenic, cadmium, copper, mercury, selenium, and zinc in soil were all highly correlated. Concentrations of arsenic, cadmium, copper, mercury, selenium, and silver in Cranberry Portage did not differ significantly from concentrations in The Pas, indicating that smelter emissions may not have a significant influence on conditions in Cranberry Portage (Manitoba Conservation, 2006).

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 (1994a) studies, 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 anticipated to result in human health concerns for individuals consuming home garden produce (Manitoba Conservation, 2006).

Of these three primary studies, the Manitoba Conservation report (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 (1994a) 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.

4.2 Data Gap Analysis

Although the Manitoba Conservation (2006) report included a home garden sampling location (TQ0164) directly south of the HBMS complex, one was not selected within the town of Creighton. Given that the tailings impoundment is located directly north of Creighton, there is uncertainty as to whether or not the garden plots in this report are representative of the potential influence of wind-blown tailings on home gardens in Creighton. Given that the HBMS (1994a) study did include a home garden within Creighton, results from this study may need to be considered in the HHRA, however, values are not available for all metals that may be retained for evaluation.

4.0 DRINKING WATER DATA

5.1 Summary of Review

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.

The most complete set of data for metal analysis in drinking water is the HBMS monthly sampling of drinking water taken from the Vocational Centre in Flin Flon. However, these data may not be appropriate for use in the HHRA to predict exposure to the general population because an additional filter is present at this sampling location and results may not be representative of the content of water within community-wide distribution. Three other sources of Flin Flin drinking water data are available, likely collected as part of Manitoba Conservation or other Provincial monitoring programs. Concentrations of antimony, arsenic, cadmium, copper, lead, molybdenum, selenium, silver, thallium, and zinc are provided for treated Flin Flon drinking water from 2002 to 2006 (Table 5-1). Concentrations of these metals are relatively consistent across this sampling period 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.

Table 5-1 Concentrations of Metals in Treated Drinking Water for Flin Flin from 2002 to 2006 (µg/L total metals)

Chemical	*2002*	*2003*	*2004*	*2005*	*2006*
Antimony	0.7	0.6	0.6	0.6	0.5
Arsenic	1.9	2.0	1.8	2.5	2.3
Cadmium	0.68	0.61	0.65	0.61	0.92
Copper	21	21	48	45	69
Lead	0.7	0.3	0.6	1.5	3.2
Molybdenum	<0.1	<0.1	<0.1	<0.1	<0.1
Selenium	<0.2	<0.2	<0.2	<0.2	<0.2
Silver	<0.02	<0.02	<0.05	<0.05	<0.05
Thallium	<0.02	<0.02	<0.02	<0.02	<0.02
Zinc	140	95	110	86	85

Saskatchewan Environment (2006) has provided data for the Creighton Distribution System. The most recent data are for 2005 and 2006 in which concentrations (one per year) are provided for arsenic, cadmium, copper, lead, mercury, selenium, and zinc (Table 5-2). Concentrations of copper and lead in the Creighton drinking water are notably lower than those in Flin Flon drinking water during the same period.

Table 5-2 Concentrations of Metals Measured in the Creighton Distribution System in 2005 and 2006 (µg/L total)

Chemical	*February 2005*	*June 2006*
Arsenic	2.2	1.4
Cadmium	<0.5	0.4
Copper	13	3
Lead	<0.1	<0.1
Mercury	-	<0.05
Selenium	0.2	0.1
Zinc	110	46

5.2 Data Gap Analysis

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 Stephen West and Joel Nilsen of HBMS on August 28, 2007, HBMS 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 11 metals that are anticipated to be evaluated in the HHRA (*i.e*., antimony, arsenic, cadmium, copper, lead, mercury, molybdenum, selenium, silver, thallium, and zinc).

5.0 FISH AND SEDIMENT DATA

6.1 Summary of Review

Given that sport-fishing during both the summer and winter months is an important recreational activity in Flin Flon and Creighton, consumption of local fish may be a potentially significant route of exposure to metals released by the HBMS complex. When assessing exposure to chemicals as a result of the consumption of fish, there are several important factors to consider. Characterizing the concentrations of metals in fish should focus on those tissues, which are most likely to be consumed by humans. While many studies include the analysis of concentrations in both liver and muscle tissue, it is common to assume that humans will generally only consume the muscle tissues and discard the organs and skin. Predicting concentrations of metals in muscle tissue based on measured concentrations in surface water and sediment can often be problematic due to several confounding factors associated with site-specific conditions and the limited rates of accumulation of many metals. Significant uncertainty can be reduced through the collection and analysis of fish tissues collected from lakes that are known to be frequented by local fishermen. Concentrations of metals within the tissues of fish from Flin Flon area lakes were documented in two separate studies. However, one of the studies focused on Ross and Schist Lakes which are known to be heavily influenced by liquid effluent from the HBMS complex as well as significant historic releases of sewage. As a result, use of fish data collected from either of these lakes may not be an accurate representation of levels that residents of Flin Flon or Creighton may be exposed to over a chronic duration due to public awareness of contamination in these lakes.

A 1982 study involved a survey of lakes that were considered to be within the deposition zone of the smelter (Harrison *et al*., 1989; Harrison and Klaverkamp, 1990). Liver and skeletal muscle from white sucker (*Catostomus commersoni*) and northern pike (*Esox lucius*) were analyzed for arsenic, copper, cadmium, mercury, lead, selenium, and zinc. Thirteen lakes were sampled: five lakes from within an 8 km radius of the smelter (Flin Flon lakes); four lakes from 23 to 43 km east of the smelter (Manitoba lakes), and four lakes from 68 to 84 km northwest of the smelter (Saskatchewan lakes). Sediment cores were also collected and analyzed for copper, cadmium, mercury, selenium, and zinc in 1985 (three years after significant reductions in smelter emissions) (Table 6-1). Surface water samples were not taken because metal contamination within aquatic ecosystems is generally more accurately reflected in sediment composition. It was believed that measurements of metals in sediments would be a better predictor of contamination in biological tissues than surface water would be (Harrison and Klaverkamp, 1990).

Table 6-1 Summary of Mean Concentrations of Metals within the Top 2 cm of Sediments (µg/g d.w)

Group	*Lake*	*Distance (km)*	*Zinc*	*Copper*	*Cadmium*	*Mercury*	*Selenium*
Flin Flon	Hamell	4.5	8408	2775	56	3.27	11.1
	Douglas	5	12625	1900	60	3.77	12.6
	Phantom	5.4	6988	1385	36	9.22	4.5
	Cliff	5.6	5950	1278	21	6.39	4.0
	Meridian	7.6	2858	568	15	2.69	3.4
Manitoba	Cleaver	23	1238	198	7	1.30	2.5
	Naosap Mud	27	282	49	2	0.10	1.4
	Kotyk	30	507	76	3	0.35	2.4
	Nekik	43	170	34	<1	0.09	1.0
Saskatchewan	1	68	118	44	<1	0.11	0.9
	2	74	175	41	<1	0.14	1.3
	3	83	46	13	<1	0.03	0.2
	4	84	142	57	<1	0.22	0.9

The results of the sediment sampling indicated that the area receiving significant deposition of metals is likely much smaller than originally estimated by Franzin *et al*. (1979). Concentrations of metals in surface sediments of Saskatchewan lakes (68 to 84 km from the smelter) were equal to or less than lakes located in Ontario removed from significant anthropogenic sources. Based on the ratio of surface sediment to background concentrations of metals in sediments, it appears that the limit of deposition to the east was approximately 43 km as indicated by analysis of sediments in Nekik Lake (Harrison and Klaverkamp, 1990).

Generally, concentrations of most metals were found to be highest in the liver of fish from Flin Flon lakes (Harrison and Klaverkamp, 1990). While concentrations of metals such as cadmium, copper, selenium, and zinc were higher in the liver of fish from Flin Flon, relative to Saskatchewan, the opposite was true for mercury. Concentrations of mercury in the liver of both northern pike and white sucker were significantly higher in Saskatchewan lakes than in Flin Flon lakes. A similar pattern was observed in Sudbury, where concentrations of mercury in crayfish and perch were lower with increased proximity to the smelter. This was attributed to two factors. First, selenium has been reported to inhibit the accumulation of mercury by fish, therefore, increased concentrations of selenium in lakes closest to the smelter can have a significant impact on mercury accumulation. Secondly, methylmercury represents the largest component of total mercury within the tissues of fish. It has been reported that elevated concentrations of copper, cadmium, and zinc in sediments reduces the methylation of mercury (Jackson, 1984). This was supported by Harrison and Klaverkamp (1990) in which the highest concentrations of mercury in fish were associated with the lowest concentrations of copper, cadmium, selenium, and zinc in sediments. Although concentrations of some metals were elevated within liver tissues, as discussed previously, the HHRA would likely focus on concentrations within the muscle tissues only.

Concentrations of metals in muscle tissue were not consistently higher in fish sampled from the Flin Flon lakes (Table 6-2). Concentrations of zinc in the muscle of white sucker were significantly higher in Flin Flon lakes relative to Saskatchewan lakes. Concentrations of cadmium in muscle tissue were below detection in all lakes with the exception of northern pike from Cliff Lake. Concentrations of lead and arsenic were below detection limits (<0.02 and <0.05 µg/g, respectively) in almost all lakes sampled. Detectable concentrations of arsenic were generally only found in lakes closest to the smelter. Concentrations of metals in the muscle of northern pike and the liver of white sucker were not significantly correlated with concentrations in sediments. However, concentrations of selenium in the liver of northern pike were positively correlated with selenium in sediment.

Table 6-2 Mean Concentrations of Metals in the Muscle Tissue of Northern Pike and White Sucker (ug/g w.w)

Group	*Species*	*Zinc*	*Copper*	*Cadmium*	*Mercury*	*Selenium*
Flin Flon	Northern Pike	5.6	0.16	<0.01	0.09	0.88
	White Sucker	5.5	0.22	<0.01	0.02	1.05
Manitoba	Northern Pike	5.1	0.12	<0.01	0.22	0.20
	White Sucker	3.0	0.25	<0.01	0.03	0.22
Saskatchewan	Northern Pike	5.7	0.22	<0.01	0.47	0.29
	White Sucker	3.5	0.34	<0.01	0.06	0.28

Overall, the Harrison Klaverkamp (1990) study found that concentrations of metals in muscle tissue were not consistently higher in fish sampled from the Flin Flon lakes. Generally, the results of the study indicated that concentrations of metals found in fish from the area surrounding the smelter were similar to concentrations observed in fish from remote lakes from the Precambrian shield of Ontario, which have not been impacted by anthropogenic sources. Concentrations in fish tissues were generally not directly proportional to concentrations in sediments. Results were generally similar to those observed in Sudbury (Harrison and Klaverkamp, 1990).

A limnological survey of Ross Lake and Schist Lake was completed by HBMS in 1994. Sediment samples were collected from the top 5 cm using an Ekkman Box Corer (Table 6-3) (HBMS, 1994b).

Table 6-3 Maximum Concentrations of Metals in Sediment of Ross and Schist Lake (µg/g)

Chemical	*Ross Lake*	*Schist Lake*
Arsenic	316	596
Cadmium	769	481
Copper	20,300	11,270
Lead	385	235
Mercury	179	12
Zinc	64,700	91,100

As a part of this survey, fish were collected from Schist Lake and analyzed for metal content in liver and muscle tissue. Of the eleven metals of concern for the HHRA, six were analyzed for in fish samples: arsenic, cadmium, copper, mercury, lead, and zinc. Fish samples were collected in July/August, 1994 (Table 6-4) and in October, 1994 (Table 6-5) using gill nets. Individual specimens were analyzed for metals in muscle tissue and liver tissue when sufficient tissue was available. Homogenizing of samples occurred when necessary. A total of 68 specimens were captured (HBMS, 1994b).

Table 6-4 Concentrations of Metals in the Tissues of Fish from Schist Lake Sampled in August, 1994 (μg/g)

Species	*Tissue*	*Parameter*	*Copper*	*Zinc*	*Lead*	*Cadmium*	*Mercury*	*Arsenic*
Northern Pike (n=5)								
	Muscle	Mean	1.0	8.5	0.3	<0.1	0.047	0.046
		Max	2.7	12.1	0.5	<0.1	0.078	0.098
	Liver	Mean	22.1	39.6	<0.3	<0.1	0.056	0.029
		Max	28.9	51.2	<0.3	<0.1	0.093	0.068
Walleye (n=1)								
	Muscle	Mean	-	-	-	-	-	-
		Max	0.6	6.0	<0.3	<0.1	0.064	0.065
	Liver	Mean	-	-	-	-	-	-
		Max	7.4	21.1	<0.3	0.5	0.04	0.11
Cisco (muscle n=12, liver n=6)								
	Muscle	Mean	0.8	9.7	<0.3	<0.1	0.031	0.04
		Max	1.1	23.9	<0.3	<0.1	0.078	0.08
	Liver	Mean	6.9	18	<0.3	0.2	0.148	0.140
		Max	12.6	34.2	<0.3	0.3	0.690	0.194
Lake Whitefish (muscle n=2, liver n=1)								
	Muscle	Mean	0.5	6.1	0.4	<0.1	0.026	0.042
		Max	0.5	6.2	0.4	<0.1	0.026	0.063
	Liver	Mean	-	-	-	-	-	-
		Max	7.1	22.1	<0.3	0.4	0.330	0.119

Table 6-5 Concentrations of Metals in the Tissues of Fish from Schist Lake Sampled in October, 1994 (μg/g)

Species	*Tissue*	*Parameter*	*Copper*	*Zinc*	*Lead*	*Cadmium*	*Mercury*	*Arsenic*
Northern Pike (n=19)								
	Muscle	Mean	0.8	5.9	0.3	0.1	0.028	0.020
		Max	1.3	8.6	0.5	0.3	0.074	0.028
	Liver	Mean	10	38.5	<0.3	0.1	0.018	0.019
		Max	20.2	59	<0.3	0.6	0.028	0.035
White Sucker (muscle n=4, liver n=2)								
	Muscle	Mean	0.7	4.9	0.3	0.2	0.011	0.025
		Max	0.8	5.7	0.4	0.2	0.015	0.039
	Liver	Mean	7.9	32.7	0.5	0.3	0.034	0.053
		Max	9.4	34.1	0.7	0.3	0.037	0.067
Cisco (muscle n=21, liver n=10)								
	Muscle	Mean	0.5	5.4	0.3	0.2	0.012	0.031
		Max	0.7	7.2	0.4	0.4	0.02	0.045
	Liver	Mean	4	21.7	0.4	0.3	0.018	0.068
		Max	15.7	44.5	1.0	0.7	0.020	0.094
Lake Whitefish (muscle n=4, liver n=2)								
	Muscle	Mean	0.5	5.4	0.3	0.1	0.011	0.029
		Max	0.6	6.0	0.4	0.2	0.015	0.040
	Liver	Mean	5.9	27.3	0.5	0.6	0.056	0.044
		Max	6.4	28	0.7	0.7	0.058	0.042

While this study offers important insight into the movement of metals within this water system and the impact on fish within this environment, the northern basin of Ross Lake receives treated alkaline effluent overflow through Flin Flon Creek from HMBS tailings ponds, and Schist Lake receives water from Ross Lake *via* Ross Creek. In addition, water quality in Ross Lake is well known to be heavily compromised as a result of historic sewage discharge, therefore, the relevance of using fish data for these lakes for the HHRA must be further assessed.

6.2 Data Gap Analysis

Both studies described are relatively old and data may not be an accurate reflection of current levels in fish from the Flin Flon and Creighton area. Although concentrations in fish from the 1982 survey do not appear to be significantly elevated above background levels, concentrations of copper and zinc in muscle tissue from Schist Lake measured in 1994 were significantly higher than those reported in the 1982 survey. Lack of current data may create an area of uncertainty for the HHRA. In addition, concentrations of antimony, molybdenum, silver, and thallium in fish tissues have not been reported in any of the studies reviewed. Since there are several factors that influence the uptake of metals from the surrounding aquatic environment into the tissues of fish, it is recommended that tissue concentrations not be predicted based on more recent measurements of metals in sediments and surface water, rather measured data is preferred. This recommendation is supported by the findings of the 1982 survey which concluded that concentrations in fish were not proportional to concentrations in sediments.

6.0 SURFACE WATER DATA

7.1 Summary of Review

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).

As part of the Environmental Effects Monitoring (EEM) report, surface water samples were collected from reference and exposure areas associated with the Flin Flon tailings impoundment system (FFTIS) discharge (the North Weir) and the Trout Lake mine discharge, both of which discharge into Flin Flon Creek (Stantec, 2005). Maximum surface water concentrations from exposure areas (E) (at or downstream of the discharge areas) and reference areas (R) (similar characteristics to the exposure areas but unaffected by the discharge) are presented in Table 7-1. Samples were collected in September, 2004.

Table 7-1 Maximum Surface Water Concentrations Measured in Areas Affected by HBMS Discharge and Selected Reference Areas (µg/L)

Chemical	*Beaver Dam Creek (R)*	*North Weir (E)*	*Flin Flon Creek (R)*	*Flin Flon Creek (E)*	*Ross Creek (E)*	*Phantom Lake (R)*	*Schist Lake (E)*
Arsenic	4.4	3.1	3.9	4	5.8	7.9	3.4
Cadmium	2.15	1.19	1.88	2.18	7.9	0.2	1.2
Copper	242	80	89	79	237	9	86
Lead	5.5	2.2	2.8	2.4	15.6	3.2	2.2
Mercury	<0.05	<0.05	<0.05	<0.05	0.1	0.06	0.05
Molybdenum	0.3	10.7	9.7	9	6.3	7	11
Zinc	610	330	390	480	920	140	280

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 in the exposure areas of the EEM 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.

Concentrations of selected metals in the surface water of Douglas Lake were provided by Saskatchewan Environment (1993). Douglas Lake is an important resource to the town of Creighton because it serves as the raw source of municipal drinking water. However, the most recent data provided for Douglas Lake is for 1993 in which only arsenic and zinc were found above the laboratory detection limit (Table 7-2).

Table 7-2 Concentrations of Total Metals in Surface Water of Douglas Lake in August, 1993

Chemical	***Concentration (µg/L total)***
Arsenic	8
Cadmium	<1
Copper	<1
Lead	<5
Molybdenum	<5
Selenium	<1
Silver	<1
Zinc	82

7.2 Data Gap Analysis

Recent surface water concentrations are limited for lakes in the Flin Flon and Creighton areas that are likely to be used for ongoing recreational activities such as swimming. However, given that dermal uptake of metals from surface water is not anticipated to be a significant exposure pathway relative to soil-related pathways, concentrations provided for the three reference areas in the EEM report may be sufficient to address this pathway in the HHRA. The EEM study did not measure concentrations of antimony, selenium, silver, or thallium in surface water.

7.0 BLUEBERRY DATA

8.1 Summary of Review

Four studies were reviewed in which concentrations of metals in blueberries in Flin Flon were described (Wotton, 1979; Shaw, 1981; McEachern and Phillips, 1983; Manitoba Conservation, 2000). With the exception of Shaw (1981), these studies only measured concentrations of mercury and lead. It was generally observed that the greater concentrations were located in close proximity to the smelter, although no statistically significant trends were measured to support this.

Sampling conducted in 2000 by Manitoba Conservation reported lower metal concentrations than those measured between 1978 to 1981 (Wotton, 1979; Shaw, 1981; McEachern and Phillips, 1983). Mercury concentrations for washed berries were <0.01 µg/g (dry weight) for all samples taken from 13 locations in 2000 at distances ranging from 1.95 km to 155 km from the smelter (Table 8-1). In samples taken between 1978 and 1981, mercury concentrations for unwashed berries ranged from 0.01 to 0.22 µg/g (dry weight) and <0.02 to <0.10 µg/g (dry weight) for washed berries (Wotton, 1979; Shaw, 1981; McEachern and Phillips, 1983). These values were similar to background concentrations for unwashed (0.02 to 0.09 µg/g dry weight) and washed berries (<0.03 to <0.07µg/g) (Wotton, 1979; Shaw, 1981; McEachern and Phillips, 1983). Generally, the washed berries had only slightly lower concentrations than the unwashed berries.

As part of the Manitoba Conservation study in 2000, 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. The highest concentrations of lead in unwashed blueberries (7.0 and 7.26 µg/g dry weight) were reported by Shaw (1981) from two samples taken in 1978 from a site 2.4 km southeast of the smelter. Concentrations of lead in blueberries in sites beyond 25 km of the smelter could not be determined analytically in the latter study.

Background concentrations of lead in berries sampled between 1978 and 1981 reported by Wotton (1979) and McEachern and Phillips (1983) exceeded the maximum concentration measured in 2000 (0.3 µg/g, dry weight, washed). Wotton (1979) reported background concentrations of <1.20 and <1.25 µg/g dry weight, washed and unwashed, respectively. The lead concentrations reported from non-reference sites in this study did not exceed the background concentrations to a great extent, with dry weight concentrations ranging from 1.18 to 2.42 µg/g (washed), and 1.16 to 2.43 µg/g (unwashed). McEachern and Phillips (1983) reported lead concentrations ranging from 0.61 to1.9 µg/g (dry weight, washed), and 0.94 to 1.6 µg/g (dry weight, unwashed) at a control site. Lead concentrations measured from sites not designated as background in this study ranged from 1.6 to 5.0 µg/g (washed) and 1.7 to 5.2 µg/g (unwashed). Many of the concentrations measured prior to 1990 exceeded the average lead concentrations in Canadian berries (0.05 µg/g) (McEachern and Phillips, 1983).

Table 8-1 Maximum Concentrations of Lead and Mercury in Washed Blueberries Sampled from 13 Locations in the Flin Flon Area (µg/g d.w.)

Location	*Date Sampled*	*Lead*	*Mercury*
TQ0151	08/15/2000	< 0.1	< 0.01
TQ0152	08/15/2000	< 0.1	< 0.01
TQ0153	08/16/2000	< 0.1	< 0.01
TQ0154	08/16/2000	< 0.1	< 0.01
TQ0155	08/15/2000	< 0.1	< 0.01
TQ0156	08/15/2000	< 0.1	< 0.01
TQ0157	08/15/2000	0.3	< 0.01
TQ0158	08/15/2000	< 0.1	< 0.01
TQ0159	08/15/2000	< 0.1	< 0.01
TQ0160	08/15/2000	< 0.1	< 0.01
TQ0161	08/15/2000	0.3	< 0.01
TQ0162	08/15/2000	< 0.1	< 0.01
TQ0163	08/17/2000	< 0.1	< 0.01

Only one study (Shaw, 1981) measured concentrations of metals other than lead and mercury in blueberries. A total of three sites were surveyed, with concentrations of arsenic, cadmium, copper, lead, mercury, molybdenum, selenium, silver, thallium and zinc measured. Concentrations of arsenic, copper, lead, mercury, selenium, and zinc were notably higher in blueberries sampled from the site in closest proximity to the smelter compared to two sites at beyond 25 km (Table 8-2).

Table 8-2 Concentrations (µg/g d.w.) of Various Elements in Blueberries in Flin Flon at Select Distances from the HBMS Complex

Chemical	*Sample Locations*[a]		
	Louis Lake (2.4 km SE)	*Mystic Creek (26.5 km SE)*	*Cranberry Portage (36.2 km SE)*
Arsenic	1.74 - 2.0 [b]	0.31	0.16
Cadmium	ND	ND	ND
Copper	21.1	3.7	3.7
Lead	7.0 - 7.26[b]	ND	ND
Mercury	0.22	0.01	0.02
Molybdenum	ND	ND	ND
Selenium	<0.2 - 0.22[b]	<0.03	0.07
Silver	0.5	ND	15
Thallium	ND	ND	ND
Zinc	24	ND	ND

[a] One sample was taken at each location
[b] Concentrations reported by two different labs (n=2)

8.2 Data Gap Analysis

Given that the Manitoba Conservation (2000) report provides the most recent and robust set of data for concentrations of lead and mercury in blueberries, it is anticipated that this will serve as the primary source of information for these chemicals in the HHRA. However, concentrations are not provided for the remaining nine metals which were identified as being elevated in soils in the 2006 soils study. 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 the sampling site located in close proximity to the smelter relative to the reference locations.

Based on personal communications with HBMS staff, it is understood that it is common for some residents of Flin Flon and Creighton to pick large amounts of blueberries to be consumed over the course of the entire year. Although it is anticipated that a significant portion of the blueberry harvest will be collected from areas that are not immediately adjacent to the smelter and may not be significantly impacted by smelter-related emissions, a detailed evaluation of this exposure pathway in the HHRA is likely warranted. Given that the use of generic uptake factors to predict concentrations in berries from measured soil concentrations may not accurately account for site-specific conditions and variables, analysis of the metal content of local blueberries would help to significantly reduce uncertainty associated with the assessment of this exposure pathway.

8.0 CONCLUSIONS

Based on the review of the available resources to date, the collection of supplemental data may help to reduce uncertainty associated with predicting exposure to metals in certain environmental media (Table 9-1). 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 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 dose.

To address data gaps in ambient air data, HBMS has agreed to expand the list of chemicals to be analyzed in the PM_{10} component of samples. Although HBMS has agreed to test for all 11 metals of potential concern associated with PM_{10} at the Ruth Betts and Creighton Schools, the absence of these data from the Provincial Building may create 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 (2006) 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 also arranged to address gaps in drinking water data by sampling water from a residential location in Flin Flon and a residential location in Creighton and provide a weekly analysis of the content of all 11 metals that may be evaluated in the HHRA.

A lack of current data describing metal content in the edible tissues of local fish may create an area of uncertainty for the HHRA. In addition, concentrations of antimony, molybdenum, silver, and thallium in fish tissues have not been reported in any of the studies reviewed. Since many metals do not show a strong tendency for accumulating in the edible tissues of fish, this may not be a critical data gap for predicting overall exposures. Although recent surface water concentrations are limited for lakes in the Flin Flon and Creighton areas that are likely to be used for ongoing recreational activities such as swimming, dermal uptake of metals from surface water is not anticipated to be a significant exposure pathway relative to soil-related pathways, this also may not be a critical data gap for predicting overall exposures.

Finally, information regarding concentrations of metals in local blueberries are essentially limited to lead and mercury, which were nearly all below detection. However, there is 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 may be warranted to address potential public concern.

Table 9-1 Summary of Data Gaps and Recommendations

Environmental Medium	***Data Gaps***	***Recommendation***
Soil and Dust	- limited residential soil data - no indoor dust data - no bioaccessibility data	- collect soil samples from front and backyards of residential properties - collect indoor dust samples from homes and schools - conduct in-vitro bioaccessibility studies on soil and dust samples
Air	- current air sampling data does not contain measurements of all metals of potential 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	- collect data from locations representative of drinking water in Creighton and Flin Flon and analyze for all metals of potential concern
Fish and Sediment	- lack of current data for all metals in edible tissues of fish from lakes likely used for recreational activities	- collect fish samples from local fishermen and analyze for all metals of potential concern in muscle tissue
Surface Water	- lack of current data for all metals in surface water from lakes likely used for recreational activities	- exposure *via* direct contact with surface water is likely minor; no additional sampling is required
Blueberries	- limited data for metals other than lead and mercury	- collect blueberry samples and analyze for all metals of potential concern

Although data may be limited or absent for certain metals in some media, these deficiencies may not be relevant if these chemicals are not retained as chemicals of concern (COCs) for the HHRA or it is determined that certain pathways are not a significant source of exposure. The selection of the COCs will be a component of the Terms of Reference to be completed in combination with the current report as part of the initial Problem Formulation of the HHRA.

9.0 REFERENCES

Franzin, W.G. 1984. Aquatic contamination in the vicinity of the base smelter at Flin Flon, Manitoba, Canada- a case history. In Environmental Impacts of Smelters. Edited by J.O. Nriagu. John Wiley and Sons, New York, pp. 523- 550. Cited In: McMartin *et al*., 1999.

Franzin, W.G., McFarlane, G.A., and Lutz, A. 1979. Atmospheric fallout in the vicinity of a base metal smelter at Flin Flon, Manitoba, Canada. Environmental Science and Technology, 13(12): 1513- 1522. Cited In: Henderson *et al*., 1998.

Harrison, S.E., and J.F. Klaverkamp. 1990. Metal Contamination in Liver and Muscle of Northern Pike (*Esox lucius*) and White Sucker (*Catostomus commersoni*) and in Sediments from Lakes near the Smelter at Flin Flon, Manitoba. Environmental Toxicology and Chemistry. Vol. 9, pp.941- 956.

Harrison, S.E., M.D. Dutton, R.V. Hunt, J.F. Klaverkamp, A. Lutz, W.A. Macdonald, H.S. Majewski, and L.J. Wesson. 1989. Metal Concentrations in Fish and Sediment from Lakes near Flin Flon, Manitoba. Canadian Data Report of Fisheries and Aquatic Sciences No. 747. Department of Fisheries and Oceans, Winnipeg, Manitoba.

HBMS. 1994a. Heavy Metals in Flin Flon Area Gardens. Hudson Bay Mining and Smelting (unpublished 1994)

HBMS. 1994b. Ross-Schist Lake Limnological Survey 1994 Final Report. Hudson's Bay Mining and Smelting Environment Department (unpublished 1994).

Henderson, P.J. 1995. Surficial geology and drift composition of the Annabel Lake- Amisk Lake area, Saskatchewan (NTS 63L/9, and part of 63K/12 and K/13). Geological Survey of Canada, Open File 3026. Cited In: McMartin *et al*., 1999.

Henderson, P.J., and McMartin, I. 1995. Mercury Distribution in Humus and Surficial Sediments, Flin Flon, Manitoba, Canada. Water, Air, and Soil Pollution 80: 1043-1046.

Henderson, P.J., McMartin, I., Hall, G.E., Percival, J.B., and Walker, D.A. 1998. The chemical and Physical Characteristics of Heavy Metals in Humus and Till in the Vicinity of the Base Metal Smelter at Flin Flon, Manitoba, Canada. Environmental Geology 34 (1).

Hogan, G.D., and Wotton, D.L. 1984. Pollutant distribution and effects in forests adjacent to smelters. Journal of Environmental Quality 13 (3): 377- 382. Cited In: Henderson *et al*., 1998.

Jackson, T.A. 1984. Effects of inorganic cadmium, zinc, copper, and mercury on methyl mercury production in polluted lake sediments. Evidence for selective inhibition and stimulation of microbial species based on variations in heavy metal tolerance. In J.O Nriagu, ed., Environmental Impacts of Smelters. John Wiley and Sons, New York, NY, pp. 551- 578. Cited In: Harrison and Klaverkamp, 1990.

Manitoba Conservation 2000 (Unpublished). Manitoba Conservation Blueberry Study.

Manitoba Conservation. 2003 (unpublished). Manitoba Conservation Forest Sites Soil Data (1998/1999 and 2003).

Manitoba Conservation. 2006. Metal Concentrations in Soils and Produce from Gardens in Flin Flon, Manitoba, 2002. Geoff Jones and Vicki Henderson. Manitoba Conservation, April 2006. Report No. 2006-01

Manitoba Conservation. 2007. Concentrations of Metals and Other Elements in Surface Soils of Flin Flon, Manitoba and Creighton, Saskatchewan, 2006. Manitoba Conservation. Report No. 2007-01. http://www.gov.mb.ca/conservation/wildlife/managing/pdf/flinflon_metalcon2.pdf

McEachern, D.B. and S.F. Phillips. 1983. Monitoring for Mercury and Lead in Blueberry Plants (*Vaccinium myrtilloides* (*Michx*)) of the Flin Flon area, 1980 and 1981. Terrestrial Standards and Studies, Environmental Management Services Branch, Department of Environment and Workplace Safety and Health. Report 83-12. December, 1983

McMartin, I., Henderson, P.J., Nielsen, E., and Campbell, J.E. 1996. Surficial geology, till and humus composition across the Shield Margin, north-central Manitoba and Saskatchewan: geo-spatial analysis of a glaciated environment. Geological Survey of Canada, Open File 3277. Cited In: McMartin *et al*., 1999.

McMartin, I., Henderson, P.J., and E. Nielsen. 1999. Impact of a Base Metal Smelter on the Geochemistry of Soils of the Flin Flon Region, Manitoba and Saskatchewan. Can. J. Earth Sci. 36: 141-160.

Pip, E. 1991. Cadmium, Copper, and Lead in Soils and Garden Produce near a Metal Smelter at Flin Flon, Manitoba. Bull. Environ. Contamin. Toxicol. (1991) 46: 790-796.

Saskatchewan Environment. 1993. Douglas Lake Surface Water Data (1993). Saskatchewan Environment, Environmental Protection Branch. Provided by George Bihun, Environmental Officer.

Saskatchewan Environment. 2006. Creighton Distribution System Water Data (2005 and 2006). Saskatchewan Environment, Environmental Protection Branch. Provided by George Bihun, Environmental Officer. Also available online: http://www.saskh20.ca/mydrinkingwaterdata.asp

Shaw, G. 1981. Concentrations of Twenty-Eight Elements in Fruiting Shrubs Downwind of the Smelter at Flin Flon, Manitoba. Environmental Pollution (Series A) 25: 197-209.

Stantec. 2005. Metal Mining Environmental Effects Monitoring. FFTIS and Trout Lake Mine Initial Monitoring Program. Final Report. Stantec Consulting Ltd. June 2005.

Steiness, E., and Njastad, O. 1993. Reasons for the enrichment of metals in the organic surface layer of natural soils. In Proceedings, 9th International Conference on Heavy Metals in the Environment. Edited by R.J. Allan and J.O. Nriagu. CEP Consultants Ltd., Edinburgh, U.K., Vol. 2, pp. 226- 229. Cited In: McMartin *et al*., 1999.

Stevenson, F.J. 1994. Humus chemistry: genesis, composition, re-actions. John Wiley and Sons, Inc., Toronto. Cited In: McMartin *et al*., 1999.

Wotton, D.L. 1979. A survey of Mercury and Lead in Vaccinium myrtilloides (Michx.) of the Flin Flon Area. Manitoba Department of Mines, Natural Resources and Environment, Environmental Research and Development Branch. Report 79-3: 17pp. 1979.

Zoltai, S. 1988. Distribution of base metals in peat near a smelter at Flin Flon, Manitoba. Water, Air, Soil Pollution (37): 217- 228. Cited In: Henderson *et al*., 1998.

APPENDIX A

LITERATURE REVIEW SUMMARIES

APPENDIX A: LITERATURE REVIEW SUMMARIES

Summaries and comments on individual papers and resources reviewed as part of the literature review and data gap analysis are provided in the following sections.

A-1.0 SOIL DATA

Concentrations of Metals and Other Elements in Surface Soils of Flin Flon, Manitoba and Creighton, Saskatchewan, 2006.
Manitoba Conservation. 2007. Report No. 2007-01.

Objective: To determine the concentration and distribution of metals and other elements in the surface soils of Flin Flon, Manitoba and Creighton, Saskatchewan.

Summary: Manitoba Conservation conducted a surface soil sampling program in August 2006 which involved the collection of soil from 93 sites in Flin Flon and 13 sites in Creighton. 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.

The results of this study indicated that concentrations of the following twelve chemicals were found to be elevated relative to concentrations measured in the Cranberry Portage reference area:

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

In addition to the finding that concentrations of these compounds were elevated across much of the study area, they were also strongly inter-correlated and are known to be past or present constituents of the HBMS smelter emissions. When compared to the CCME soil quality guidelines and interim remediation criteria for soils under a residential or parkland scenario, concentrations of arsenic, cadmium, copper, lead, mercury, selenium, and thallium all exceeded their guidelines. Although concentrations of zinc exceeded the CCME guideline, this guideline is protective of environmental health and does not contain a human health component. Concentrations of antimony, molybdenum, silver and sulphur did not exceed their corresponding interim remediation criterion.

Comments: It is anticipated that the results of this report will form the basis of the Problem Formulation for the human health risk assessment (HHRA). Although other studies which involved the collection and analysis of soils will be considered, this report provides the most complete database and the most relevant sampling depths and locations to the HHRA. A potential area of significant uncertainty is the absence of soil samples taken from the front and backyards of residential properties. Although this study has effectively characterized concentrations in 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.

The chemical and Physical Characteristics of Heavy Metals in Humus and Till in the Vicinity of the Base Metal Smelter at Flin Flon, Manitoba, Canada.
Henderson, P.J., McMartin, I., Hall, G.E., Percival, J.B., and Walker, D.A. 1998. Environmental Geology 34 (1).

Objective: To characterize smelter-related contamination through the analysis of metals in humus and till samples taken from varying distances from the HBMS complex.

Summary: Previous studies have indicated that emissions from the smelter have resulted in elevated tree mortality, reduced growth, soil erosion, and a reduction in species diversity in areas located up to several kilometers from the smelter (Hogan and Wotton, 1984). 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). Analysis of chemical forms in previous studies have also indicated that 50 to 60% of zinc and 20 to 35% of copper in upper organic layers of forest floors were in bioavailable forms (Hogan and Wotton, 1984).

Humus and till were sampled from 23 sites. Till samples were collected from below the B soil horizon from exposed sections or from holes dug to bedrock or a maximum depth of 1 m. Humus samples were collected adjacent to or directly above the till sample. For the purposes of the current study, humus was defined as upper organic-rich portion of the soil horizon. This layer receives direct deposits of smelter-related emissions. Concentrations of metals in this layer decreased with increasing distance from the smelter. Zinc was found up to 94 times the concentration found in regional background samples at a distance of 10 km and reduced to 1.6 times regional background levels at a distance of 80 km. Concentrations of mercury reached a maximum of 500 times the regional background concentration at a distance of <5 km and reduced to 1.5 times at a distance of 40 km. Generally, concentrations of all smelter-related metals were higher in humus than in the underlying till. Concentrations in till were not directly related to distance from the smelter and were generally less variable than concentrations in humus.

Composition of till (>45 cm bgs) was generally a reflection of bedrock geology with modifications as a result of glacial erosion, transport, and deposition. The composition of humus was influenced to a greater extent by the interactions between geochemical, biogeochemical, and atmospheric processes.

Impact of a Base Metal Smelter on the Geochemistry of Soils of the Flin Flon Region, Manitoba and Saskatchewan.
McMartin, I., Henderson, P.J., and E. Nielsen. 1999. Can. J. Earth Sci. 36: 141-160.

Objective: To estimate the influence of anthropogenic contamination on concentrations of six heavy metals (arsenic, cadmium, copper, mercury, lead, zinc) in humus and till in the Flin Flon area.

Summary: The current study used the results from a regional geochemical mapping project conducted by the Geological Survey of Canada and Manitoba Energy and Mines (Henderson, 1995; McMartin *et al*., 1996) in Flin Flon, central Manitoba, and Saskatchewan. Humus and till were sampled at greater than 1,600 sites within a 200 km radius of the HBMS smelter in Flin Flon. Samples were taken at an average of spacing of 4 km, with a total of 1,817 samples of till and 1,639 samples of humus collected. Humus samples were collected directly over or immediately adjacent to the till sampling location. This study also characterized concentrations of metals representative of regional background levels by calculating the median concentrations near Snow Lake. This area is geologically similar to the Flin Flon area but is considered to be locates at a distance (<100 km) that is not influenced by emissions from the HBMS smelter.

Humus and till are influenced by atmospheric releases of gases and particulates from the smelter as well as dusts originating from tailings, exposed ore residue dumps, and ore and concentrate disturbed during transportation (Franzin, 1984). In areas not directly influenced by point source anthropogenic releases, metals that naturally occur in the environment, such as lead and mercury, tend to concentrate in humus as a result of long-term upward translocation by plant roots and accumulation through the decomposition of plant materials (Stevenson, 1994).

The results of the study indicate 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. Although these results are similar to those found through the analysis of peat samples (Zoltai, 1988), they differ from results found through the analysis of bulk precipitation (Franzin *et al*., 1979) in which a much greater area of impact was predicted (cadmium up to 284 km and zinc up to 264 km). Harrison and Klaverkamp (1990) predicted that copper, cadmium, and zinc were not transported at distances greater than 68 km to the northwest based on analysis of metals in sediments.

Although concentrations in humus are a reflection of mixing with the mineral matter and biogeochemical cycling (Steiness and Njastad, 1993), in the Flin Flon region, the primary factor is the contribution from the HBMS complex. Henderson *et al*. (1998) used a sequential extraction analysis to show that copper, cadmium, lead, and zinc are found in a highly leachable (labile) form in the soluble organic phase of humus (humic and fulvic complexes). In contrast, arsenic and mercury were found to be in less mobile nonlabile phases (humin and mineral matter).

While the concentrations of metals in humus in the Flin Flon area are primarily a reflection of the influence of the smelter, concentrations in till are more heavily influenced by the composition and nature of the bedrock and are modified by glacial erosion, transport, and deposition (McMartin *et al*., 1996).

Overall, the study found that contamination of smelter-related metals is generally restricted to the organic surface horizon (humus) and that concentrations are poorly correlated with concentrations in the underlying till. However, in close proximity to the smelter (<10 km), migration through the soil profile is significant and elevated concentrations are found to a minimum depth of 45 cm.

Determining the Cutoff Between Background and Relative Base Metal Smelter Contamination Levels using Multifractal Methods.
Sim, B.L., Frederik, P., Agterberg, P., and Beaudry, C. 1999. Computers and Geosciences 25: 1023-1041.

Objective: To demonstrate the usefulness of a multifractal model to predict break points between background and anamolous environmental concentrations by using measured values of metals in humus measured in Flin Flon.

Summary: This paper uses data collected by McMartin and Henderson to test a computer model that uses a multifractal area-concentration approach to predict the potential limits of smelter-related contamination in humus. The predicted distances from the smelter at which concentrations return to background levels support previous findings (142, 104, and 105 km from the smelter for copper, zinc, and mercury, respectively).

Mercury Distribution in Humus and Surficial Sediments, Flin Flon, Manitoba, Canada.
Henderson, P.J., and McMartin, I. 1995. Water, Air, and Soil Pollution 80: 1043-1046.

Objective: To evaluate the distribution of total mercury in humus and underlying till in the Flin Flon area.

Summary: As part of a regional surficial geological mapping project conducted by the Geological Survey of Canada, humus and surficial sediment samples were collected from the Flin Flon and Snow Lake area. Forests in this area 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). Smelter-related metals have been found to elevated in forest soil (Hogan and Wooton, 1984) and peat (Zoltai, 1988), increasing with increased proximity to the smelter. The current study focused on concentrations of total mercury which is released from the smelter as fine particles.

Humus and till samples were collected during the summers of 1992 and 1993. Till samples were collected from directly below or immediately adjacent to the overlying humus sample at depths to a maximum of 1 m. Overall, concentrations of mercury in humus were higher than those measured in till, with median concentrations of 266 ppb and 50 ppb in humus and till, respectively. Concentrations in humus were as high as 250 times the estimated background concentration of 400 ppb, whereas concentrations in till were only as high as 7 times the background concentration (60 ppb). Concentrations in humus decreased rapidly with distance from the smelter and generally returned to background levels at a distance of 35 km. Concentrations in till were relatively constant regardless of distance. The organic content of humus did not appear to be a factor in mercury content in this layer. Given that organic content in humus was low in close proximity to the smelter, it is suggested that mercury concentrations are more directly linked to deposition from the smelter rather than incorporation from the surrounding soil and organic matter.

Manitoba Conservation Blueberry Study.
Manitoba Conservation 2000 (Unpublished).

Summary: As part of a study in which concentrations of several metals were measured in blueberries collected from a number of locations in the Flin Flon area, as well as Cranberry Portage, soil concentrations from the sampling locations were also measured. A report is not available to discuss the sampling protocol or a summary of the results. Two spreadsheets were provided; one containing the data for the blueberry analysis and one containing the results of the soils analysis. Three soil samples were taken from each of 13 sites. Easting and northing coordinates are provided for each location. Samples were taken from depths ranging from 1.5 to 7 cm bgs. Descriptions of the sampling locations are provided in the table below.

Table A-1 Description of Sampling Locations within the Blueberry Sampling Study

Station	***Site Description***
TQ0151	Blue-berry Site #1, 4.91 km ESE of HBM&S smelter *via* Hwy #10
TQ0152	Blue-berry Site #2, 8.6 km ESE of HBM&S smelter *via* Hwy #10
TQ0153	Blue-berry Site #3, 15.03 km ESE of HBM&S smelter, access *via* Little Spruce Lake Rd.
TQ0154	Blue-berry Site #4, 39.4 km ESE of HBM&S smelter at Cranberry Portage lagoon
TQ0155	Blue-berry Site #5, 5.27 km SSE of HBM&S smelter *via* road along Northwest Arm of Schist Lake
TQ0156	Blue-berry Site #6, 14.55 km SSE of HBM&S smelter *via* West Arm Mine road
TQ0157	Blue-berry Site #7, 2.51 km SSE of HBM&S smelter on golf course road
TQ0158	Blue-berry Site #8, 3.88 km NNE of HBM&S smelter near radio tower at Cliff Lake
TQ0159	Blue-berry Site #9, 2.70 km ESE of HBM&S smelter at original Hillside Cemetery
TQ0160	Blue-berry Site #10, 3.14 km NE of HBM&S smelter at trans tower near off of Hwy #10
TQ0161	Blue-berry Site #11, 1.95 km NNE of HBM&S smelter E side of railroad tracks
TQ0162	Blue-berry Site #12, 35.39 km SSE of HBM&S smelter in cutover along Athapap Rd.
TQ0163	Blue-berry Site #13, 155.43 km SSE of HBM&S off east side of Hwy #10 near Springwater Rec Area

The highest of the three concentrations measured for each site are presented in the table below.

Table A-2 Summary of Maximum Soil Concentrations Found at Each Sampling Location (µg/g)

Location	***Arsenic***	***Cadmium***	***Copper***	***Lead***	***Mercury***	***Molybdenum***	***Thallium***	***Zinc***
TQ0151	180	50	2,040	1,030	6.48	<10	<10	10,100
TQ0152	47	41	1,290	901	7.67	<10	<10	6210
TQ0153	6.3	7	205	151	0.91	<10	<10	1300
TQ0154	20	4	101	91	0.47	<10	<10	750
TQ0155	88	67	1,610	1,220	14.9	<10	<10	12,900
TQ0156	36	33	776	224	3.8	<10	<10	4280
TQ0157	27	99	4,240	1,130	40.6	<10	<10	21,000
TQ0158	70	55	1,180	486	11.1	<10	<10	7980
TQ0159	120	69	2,780	1,310	28.8	<10	<10	9510
TQ0160	94	69	2,830	1,450	36.5	<10	<10	11,200
TQ0161	210	125	5,060	2,500	44.3	<10	<10	24,700
TQ0162	4.7	4	153	151	0.73	<10	<10	580
TQ0163	<0.1	1	9	31	0.36	<10	<10	72
Max	210	125	5,060	2,500	44.3	<10	<10	24,700

Metal Concentrations in Soils and Produce from Gardens in Flin Flon, Manitoba, 2002. Manitoba Conservation. 2006.

Objective: To measure concentrations of metals in garden soils and home garden produce within the city of Flin Flon and to provide an assessment of the potential human health risks associated with the consumption of home garden produce.

Summary: Manitoba Conservation designed and completed a home garden sampling program in 2002 to address public concerns raised in response to discrepancies reported in the home garden surveys completed by Pip (1991) and HBMS (1994). Nine home gardens from the Flin Flon area, located at varying distances and directions from the HBMS complex, were selected to characterize the potential influence of smelter-related emissions. In addition, a garden located in the community of Cranberry Portage was selected to be representative of an area that is minimally impacted by smelter emissions. A garden in the town of The Pas was selected to represent a non-impacted control site.

Comments: In addition to home garden produce data, this report provides a significant database of concentrations of metals in soils on residential properties. Manitoba Conservation has provided detailed spreadsheets of all soil data collected as part of this study. Three replicate soil samples were collected from each of eleven garden plots. Samples were collected from a depth of 10 cm. The locations of the garden plots are described in the following table.

Table A-3 Location and Description of Home Garden Plots

Location I.D.	*Location*	*Distance from Smelter (km)*	*Direction*
TQ0164	Flin Flon	0.90	SE
TQ0165	Flin Flon	1.71	SE
TQ0166	Flin Flon	1.21	E
TQ0167	Flin Flon	1.85	E
TQ0168	Flin Flon	1.91	SE
TQ0169	Flin Flon	2.30	E
TQ0170	Flin Flon	1.93	NE
TQ0171	Flin Flon	2.37	NE
TQ0172	Flin Flon	2.71	NE
TQ0173	Cranberry Portage	38.23	SE
TQ0174	The Pas	115.01	SE

The highest of the three replicate concentrations for each garden plot are presented in the following table.

Table A-4 Summary of Maximum Soil Concentrations Found at Each Garden Plot (µg/g)

Location	*Antimony*	*Arsenic*	*Cadmium*	*Copper*	*Lead*	*Mercury*	*Moly*	*Selenium*	*Silver*	*Thallium*	*Zinc*
TQ0164	<10	50.4	11	636	474	25.9	<4	6.3	1.1	0.3	3,120
TQ0165	<10	14.4	6.9	376	229	7.2	<4	2.8	1.7	0.2	1,690
TQ0166	<10	9.4	2.9	201	71	6.91	<4	2.1	0.3	0.1	675
TQ0167	<10	13.8	5.4	262	141	3.55	<4	1.7	0.6	0.3	1,640
TQ0168	<10	16.5	3.2	747	133	3.3	<4	1.8	1.8	0.3	1,340
TQ0169	<10	9.1	2.8	173	59	1.43	<4	1.3	0.5	0.2	743
TQ0170	<10	9.1	2.4	177	49	1.56	<4	1	0.3	0.3	1,040
TQ0171	<10	6.2	1.9	126	30	2.18	<4	0.9	0.5	0.3	741
TQ0172	<10	3.1	0.8	66	12	0.64	<4	0.4	0.1	0.2	306
TQ0173	<10	3	0.5	30	48	0.22	<4	0.3	0.1	<0.1	215
TQ0174	<10	5.3	0.3	14	8	0.04	<4	0.5	<0.1	0.1	56
Max	<10	50.4	11	747	474	25.9	<4	6.3	1.8	0.3	3,120

Although soil samples were collected from residential locations, given that they were taken 10 cm bgs, they are not likely appropriate to be used in the HHRA for direct contact pathways (*i.e.*, incidental ingestion, inhalation, and dermal contact).

Manitoba Conservation Forest Sites Soil Data (1998/1999 and 2003).
Manitoba Conservation. 2003 (unpublished).

Summary: Manitoba Conservation has provided spreadsheets containing soil data for seven) forest sites in Flin Flon and a single control site. A total of 16 samples were taken at each of the seven locations at depths ranging from 0 to 15 cm bgs. The first round of sampling at these locations occurred during the summers of 1998 and 1999. These locations were re-sampled during the summer of 2003. The sample locations are described in the following table.

Table A-5 Location and Description of Forest Soil Sampling Locations

Sample I.D.	*Distance from Smelter (km)*	*Direction*
TQ0051	4.8	Southeast
TQ0052	8.7	Southeast
TQ0053	15.2	Southeast
TQ0054	38.8	Southeast
TQ0055	5.6	South
TQ0056	14.9	South
TQ0057	36.6	South
TQ0058	67.4	Control

The highest of the 16 samples for each forest sampling area are presented in the following tables for the 1998;1999 and 2003 sampling periods. The highest measured concentrations were consistently found in the upper 0 to 6 cm within the organic layer of soil as found in Henderson and McMartin (1995) and McMartin *et al*. (1999).

Table A-6 Summary of Maximum Soil Concentrations Found at Forest Sampling Sites in 1998; 1999 (µg/g)

Location	*Arsenic*	*Cadmium*	*Copper*	*Lead*	*Mercury*	*Moly*	*Selenium*	*Zinc*
TQ0051	141	49	3010	1740	16.5	<10	14.5	15,300
TQ0052	91	40	1400	984	4.35	<10	8.5	10,300
TQ0053	36	10	351	340	2	<10	4.5	2180
TQ0054	34	8.9	270	234	0.94	<10	3.0	1120
TQ0055	210	85	1760	1140	15.5	<10	12.4	14,200
TQ0056	98	22	539	629	2.8	<10	6.2	2540
TQ0057	16	19	134	153	1.18	<10	3.0	706
TQ0058	<10	1.2	61	45	0.67	<10	1.1	326
Max	210	85	3010	1740	16.5	<10	14.5	15,300

Table A-7	Summary of Maximum Soil Concentrations Found at Forest Sampling Site in 2003 (µg/g)										
Location	***Antimony***	***Arsenic***	***Cadmium***	***Copper***	***Lead***	***Mercury***	***Moly***	***Selenium***	***Silver***	***Thallium***	***Zinc***
TQ0051	8.6	94.5	43.6	2,820	1,690	30.6	1.8	25.2	3.2	1.3	11,900
TQ0052	8.4	99.8	44.2	1,800	1,730	10.9	1.1	19.2	2.1	1.2	9,270
TQ0053	3.2	39.8	6.9	401	601	1.7	2.4	5.9	0.7	0.3	1,960
TQ0054	1.2	26.5	6.1	145	200	0.65	0.5	3.5	<0.1	0.5	774
TQ0055	7.3	101	31.7	1,700	1,280	21.3	1.6	22.2	2.3	0.9	9,160
TQ0056	4.1	37.5	20.3	596	469	2.01	0.8	5.5	1.0	0.4	2,200
TQ0057	1	18.4	5.8	104	129	0.7	9.8	2	0.2	0.1	435
TQ0058	<1	4.7	1.1	62	75.4	0.27	1.2	1.2	0.6	0.4	164
Max	8.6	101	44.2	2,820	1730	30.6	9.8	25.2	3.2	1.3	11,900

Comments: Given that humans are more likely to spend chronic exposure durations among residential, commercial, and parkland areas, concentrations in forest soils may not be relevant to the HHRA. However, should it be required that concentrations in wild game or local berries or other edible plants and fruits be predicted based on environmental concentrations, these data may represent the most appropriate basis for these calculations.

A-2.0 AIR DATA

Flin Flon Area Quarterly Airy Quality Reports
Manitoba Conservation- Air Quality Section.

Objective: Manitoba Conservation issues reports on a quarterly basis summarizing air quality in the Flin Flon area as measured by Manitoba Conservation and HBMS.

Summary: Outdoor ambient air is continuously monitored for sulphur dioxide (SO_2) and particulate matter, including associated heavy metals. Monitors are located at four sampling locations in Flin Flon and Creighton:

- Provincial Building
    - Operated by Manitoba Conservation;
- Ruth Betts School
    - Operated by HBMS;
- Sewage Plant
    - Operated by HBMS; and
- Creighton School
    - Operated by HBMS.

The quarterly reports indicate the frequency of exceedences of selected air quality criteria.

Table A-8	Annual Average Metal Concentrations Associated with PM_{10} in Ambient Air (µg/m^3)				
Location	***Lead***	***Copper***	***Cadmium***	***Zinc***	***Arsenic***
Provincial Building					
2002	-	-	-	-	-
2003	-	-	-	-	-
2004	-	-	-	-	-
2005	-	-	-	-	-
2006	-	-	-	-	-

Table A-8 Annual Average Metal Concentrations Associated with PM_{10} in Ambient Air ($\mu g/m^3$)

Location	*Lead*	*Copper*	*Cadmium*	*Zinc*	*Arsenic*
Ruth Betts School					
2002	0.15	0.35	0.02	0.56	0.02
2003	0.16	0.33	0.02	0.78	0.04
2004	0.03	0.13	0.00	0.76	0.01
2005	0.07	0.18	0.01	0.37	0.02
2006	0.06	0.13	0.02	0.13	0.02
Sewage Plant					
2002	0.12	0.23	0.02	0.31	0.03
2003	-	-	-	-	-
2004	-	-	-	-	-
2005	-	-	-	-	-
2006	-	-	-	-	-
Creighton School[a]					
2002	-	-	-	-	-
2003	0.42	0.15	0.04	0.24	0.01
2004	0.42	0.13	0.04	0.23	0.01
2005	0.42	0.13	0.06	0.36	0.01
2006	0.17	0.05	0.01	0.09	0.01

[a] Measurements are from the dichotomous air sampler.

Table A-9 Annual Average Metal Concentrations Associated with TSP in Ambient Air ($\mu g/m^3$)

Location	*Lead*	*Copper*	*Cadmium*	*Zinc*	*Arsenic*	*Mercury*
Provincial Building						
2002	0.276	0.979	0.045	2.280	0.043	-
2003	0.225	1.042	0.032	1.820	0.054	-
2004	0.109	0.980	0.015	2.457	0.038	-
2005	0.175	0.894	0.022	1.646	0.043	-
2006	0.144	0.940	0.041	2.245	0.049	-
2007[a]	0.263	1.369	0.054	1.343	0.081	-
Ruth Betts School						
2002	0.150	0.688	0.019	0.851	0.037	0.0006
2003	0.136	0.799	0.018	1.193	0.037	0.0008
2004	0.040	0.576	0.006	0.898	0.016	0.0008
2005	0.089	0.764	0.014	0.603	0.023	0.0006
2006	0.059	0.742	0.020	0.287	0.024	0.0005
2007[a]	0.086	0.874	0.025	0.593	0.044	0.0003
Sewage Plant						
2002	0.122	0.639	0.023	0.602	0.031	0.0004
2003	-	-	-	-	-	0.0004
2004	-	-	-	-	-	-
2005	-	-	-	-	-	-
2006	-	-	-	-	-	-
2007[a]	-	-	-	-	-	-

Table A-9 Annual Average Metal Concentrations Associated with TSP in Ambient Air (μg/m^3)						
Location	***Lead***	***Copper***	***Cadmium***	***Zinc***	***Arsenic***	***Mercury***
Creighton School						
2002	0.167	0.560	0.005	0.773	0.151	-
2003	0.036	0.647	0.004	0.427	0.009	0.0003
2004	0.028	0.495	0.003	0.470	0.006	0.0004
2005	0.039	0.417	0.007	0.334	0.011	0.0004
2006	0.024	0.446	0.005	0.143	0.008	0.0001
2007[a]	0.027	0.415	0.005	0.076	0.009	0.0001

[a] Concentrations are the average for data sampled from January 1 to May 31 2007.

*Note From January 1998 to mid- 2005, samples from Ruth Betts, Sewage Plant, and Creighton School were only analyzed when wind direction was from the facility.

Comments on Data:

*Note Concentrations of metals associated with the PM_{10} component are higher than those associated with TSP for the Creighton School. This is a result of the use of the dichotomous air sampler used to collect the PM_{10} data. In 2003 when the dichotomous air sampler replaced the previous air sampler, the concentrations of metals associated with PM_{10} increased significantly. This increase is a result of elevated detection limits that are used to analyze for metals in the small samples collected by the dichotomous sampler. According to HBMS, the dichotomous sampler uses an 8 cm filter that retains less particulates than the previous sampler which used a 10 cm filter.

Several metals that were identified as being elevated in soils and that have been associated with emissions from the smelter are not part of the air analysis. This includes antimony, molybdenum, selenium, silver, and thallium.

A-3.0 HOME GARDEN DATA

Metal Concentrations in Soils and Produce from Gardens in Flin Flon, Manitoba, 2002.
Jones, G. and V. Henderson. 2006. Habitat Management and Ecosystem Monitoring Section, Wildlife and Ecosystem Branch, Manitoba Conservation. Winnipeg, M.B. Manitoba Conservation Report No. 2006-01. 81 pp.

Objective: To measure concentrations of metals in garden soils and home garden produce within the city of Flin Flon and to provide an assessment of the potential human health risks associated with the consumption of home garden produce.

Summary: Manitoba Conservation designed and completed a home garden sampling program in 2002 to address public concerns raised in response to discrepancies reported in the home garden surveys completed by Pip (1991) and HBMS (1994). Nine home gardens from the Flin Flon area, located at varying distances and directions from the HBMS complex, were selected to characterize the potential influence of smelter-related emissions. In addition, a garden located in the community of Cranberry Portage was selected to be representative of an area that is minimally impacted by smelter emissions. A garden in the town of The Pas was selected to represent a non-impacted control site.

Manitoba Conservation established 2.0 m x 2.5 m plots within each garden and planted potatoes, tomatoes, beans, lettuce, and carrots in each plot in June, 2002. Plots were weeded and watered as required during the months of June and July. Potatoes, lettuce, beans, and carrots were harvested in August, and tomatoes were harvested in September. Three replicate samples of each vegetable were collected from each plot. Composite samples were collected for beans, carrots, and lettuce. Samples were restricted to the edible portion of each vegetable. To determine what fraction of the total concentration of metals could be attributed to particulates on the surface of the vegetable relative to that within the tissues, replicate samples for lettuce, tomato, and bean were divided and one half was washed in tap water while the other half was left unwashed. Three replicate soil samples were collected from each plot during the August vegetable sampling.

Analysis of soil samples indicated that mean concentrations of arsenic, cadmium, copper, lead, mercury, zinc, selenium, chromium, vanadium, and titanium were significantly higher in Flin Flon gardens than in the control site garden in The Pas. Concentrations of arsenic, cadmium, copper, mercury, selenium, and zinc were all highly correlated. Concentrations of arsenic, cadmium, copper, mercury, selenium, and silver in Cranberry Portage did not differ significantly from concentrations in The Pas, indicating that smelter emissions may not have a significant influence on conditions in Cranberry Portage.

Concentrations of arsenic, cadmium, copper, lead, mercury, selenium, and zinc in vegetables from Flin Flon were generally higher than those from The Pas. Concentrations in lettuce were typically higher than in other vegetables, followed by carrots, potatoes, beans, and tomatoes. 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 used tolerable daily intake guidelines (TDIs) and typically daily intake values to determine the amount of home garden vegetables that would need to be consumed to exceed the TDI for several age/weight classes. This assessment indicated that in most cases, the amount of vegetables that would need to be consumed to exceed the TDI was significantly higher than the typical daily intake values for these vegetables.

Overall, the 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 anticipated to result in human health concerns for individuals consuming home garden produce.

Heavy Metals in Flin Flon Area Gardens
Hudson Bay Mining and Smelting (1994)

<u>Objective</u>: To measure concentrations of smelter-related metals in soils and home garden produce in Flin Flon and Creighton and compare concentrations in home garden produce to concentrations in produce from a local grocery store.

<u>Summary</u>: In the fall of 1994, HBMS collected soil and vegetable samples from seven gardens in Flin Flon and one in Creighton. Soil samples were a composite of samples taken from multiple locations around each garden within the top 10 cm. Types of vegetables collected were limited to those available in individual gardens but generally included those representative of root, fruiting, and leafy vegetables. In addition, vegetable samples were taken from a local

grocery store and submitted for analysis to allow for a comparison to the results of the home garden survey.

HBMS found that concentrations of metals in soil and vegetables decreased with distance from the complex and that concentrations in vegetables were positively related to concentrations in soil. Concentrations in leafy vegetables, such as lettuce, cabbage, chard, and beet tops were significantly higher than those observed in other types of vegetables.

When compared to concentrations in vegetables collected from the local grocery store, mean concentrations in carrots and tomatoes from home gardens were similar. However, lettuce from home gardens had concentrations of all metals except lead that were 50 to 75% higher than lettuce from the local grocery store. Concentrations of lead in lettuce from home gardens was approximately 70% lower than lettuce from the local grocery store.

This report provides concentrations of arsenic, copper, cadmium, mercury, lead, and zinc on a dry weight basis. Data are summarized for soil, beets, beet tops, carrots, tomatoes, cabbage, lettuce, and chard. A comparison is also provided for concentrations of cadmium, copper, and lead in soil and vegetables from the current study and those reported by Pip (1991).

Cadmium, Copper, and Lead in Soils and Garden Produce near a Metal Smelter at Flin Flon, Manitoba.
Eva Pip. 1991. Bull. Environ. Contamin. Toxicol. (1991) 46: 790-796.

Objective: To examine concentrations of cadmium, copper, and lead in soils and garden produce near the Flin Flon smelter.

Summary: Wind in the Flin Flon area is predominately from the northwest to the northeast directions and has an average annual velocity of 11.1 km/hr. Approximately 34% of the time, the wind direction blows from the smelter towards the city of Flin Flon (Manfreda and Sabesky, 1987). For the current study, soil and vegetable samples were collected from home gardens at the end of the 1989 growing season at 12 locations that raged in distance from 0.29 to 12.8 km northeast to southwest of the HBMS complex. Vegetable samples were washed with Flin Flon drinking water prior to analysis. Soil samples were collected from the top 10 cm of garden soil.

Concentrations of cadmium, copper, and lead all decreased significantly with distance from the smelter. A strong intercorrelation was found for all metals in soil. A significant level of variation was noted for concentrations of metals in produce. When concentrations in all produce were pooled (untransformed data), a significant inverse relationship was noted with distance from the smelter (log transformed data). Pooled produce concentrations were also significantly correlated with concentrations in soil. Metal concentrations in soil were consistently higher than concentrations in produce, with the certain exceptions for leafy tissues. Leafy tissues had significantly higher concentrations than fruits and below ground tissues. However, concentrations in leafy tissues were not significantly correlated with concentrations in soil. This was attributed largely to aerial deposition and the large surface area to volume ratio of leafy tissues. Previous studies have indicated that lead is not readily translocated from leaves to other plant tissues (Carlson *et al*., 1976). Similarly, studies by Wotton (1979) and McEachern and Phillips (1983) found that blueberries in the Flin Flon area contained lower concentrations of metals in fruits relative to concentrations in stems, leaves, and roots.

A-4.0 DRINKING WATER DATA

Hudson Bay Mining and Smelting Drinking Water Data from the Vocational Centre

Summary: HBMS tests drinking water samples from the Vocational Centre in Flin Flon on a monthly basis. Samples are tested for arsenic, cadmium, calcium, copper, iron, lead, magnesium, manganese, potassium, sodium, and zinc. Results are available for samples collected from 1995 to 2007. HBMS bottles this water for use within its facility for drinking purposes. However, an additional filter is used prior to the collection and analysis of drinking water from this location; therefore, it is not representative of water distributed to the remainder of the community.

The results of this sampling program should not be used in the human health risk assessment to assess exposure of the general population to metals through the consumption of drinking water.

Manitoba Conservation Drinking Water Data

Summary: Manitoba Conservation has provided drinking water data for most years from 1982 to 2006. One sample per year taken at varying months was analyzed for arsenic, cadmium, copper, lead, selenium, and zinc. Although historically samples were collected from both a treated tap at the water treatment plant and from the distribution system somewhere in the community, more recent samples 2004 to 2006 are only available for the treated tap at the treatment plant. Concentrations of metals from the treated tap for 2004 to 2006 are summarized in the following table.

Table A-10 Summary of Recent Drinking Water Data for Samples Taken from a Treated Tap at the Flin Flon Water Treatment Plant (µg/L)

Date	*Arsenic*	*Cadmium*	*Copper*	*Lead*	*Selenium*	*Zinc*
September 2004	1.8	0.65	15	0.6	<0.2	100
November 2005	2.5	0.61	45	1.5	<0.2	86
June 2006	2.3	0.92	69	3.2	<0.2	85

Additional Drinking Water Data for 2000- Source Unknown

Summary: A spreadsheet which includes concentrations of a number of metals as well as general physical and chemical parameters in raw and treated water for Flin Flon, station number WD0069.00, is available for September 2000 (source unknown but likely Manitoba Conservation). A summary of the relevant data are provided in the following table.

Table A-11 Concentrations of Metals in Treated Drinking Water for Flin Flin from 2000 (µg/L total metals)

Chemical	*Treated Drinking Water*
Antimony	1
Arsenic	57
Cadmium	0.3
Copper	23
Lead	0.8
Molybdenum	0.2
Selenium	<2
Silver	<0.4
Zinc	100

Given that these data are from 2000, it is not likely appropriate for use in the HHRA unless there are no other relevant sources of data for certain metals.

Additional Drinking Water Data for 2001 to 2006- Source Unknown

Summary: A spreadsheet containing concentrations of a number of metals as well as general physical and chemical parameters for raw and treated water in Flin Flon tested by CANTEST Ltd. (community code 69.00) (source unknown but likely Manitoba Conservation). A summary of the relevant data are provided in the following table.

Table A-12 Concentrations of Metals in Treated Drinking Water for Flin Flin from 2002 to 2006 (µg/L total metals)

Chemical	***2002***	***2003***	***2004***	***2005***	***2006***
Antimony	0.7	0.6	0.6	0.6	0.5
Arsenic	1.9	2.0	1.8	2.5	2.3
Cadmium	0.68	0.61	0.65	0.61	0.92
Copper	21	21	48	45	69
Lead	0.7	0.3	0.6	1.5	3.2
Molybdenum	<0.1	<0.1	<0.1	<0.1	<0.1
Selenium	<0.2	<0.2	<0.2	<0.2	<0.2
Silver	<0.02	<0.02	<0.05	<0.05	<0.05
Thallium	<0.02	<0.02	<0.02	<0.02	<0.02
Zinc	140	95	110	86	85

Creighton Distribution System Water Data (2005 and 2006)
Saskatchewan Environment, Environmental Protection Branch Provided by George Bihun, Environmental Officer. Available online: http://www.saskh20.ca/mydrinkingwaterdata.asp

Summary: Saskatchewan Environment provided a spreadsheet with various water chemistry data. Concentrations of certain metals are provided for the Creighton Distribution System. The most recent years for which these data are provided are 2005 and 2006. These data are summarized in the following table.

Table A-13 Concentrations of Metals Measured in the Creighton Distribution System in 2005 and 2006 (µg/L total)

Chemical	***February 2005***	***June 2006***
Arsenic	2.2	1.4
Cadmium	<0.5	0.4
Copper	13	3
Lead	<0.1	<0.1
Mercury	-	<0.05
Selenium	0.2	0.1
Zinc	110	46

A-5.0 FISH AND SEDIMENT DATA

Metal Concentrations in Fish and Sediment from Lakes near Flin Flon, Manitoba.
S.E. Harrison, M.D. Dutton, R.V. Hunt, J.F. Klaverkamp, A. Lutz, W.A. Macdonald, H.S. Majewski, and L.J. Wesson. 1989. Canadian Data Report of Fisheries and Aquatic Sciences No. 747. Department of Fisheries and Oceans, Winnipeg, Manitoba.

Objective: To determine levels of metal contamination in white sucker and northern pike in lakes within the area of deposition of the Smelter.

Summary: This study was conducted in 1982 and involved a survey on lakes that were considered to be within the deposition zone of the smelter. This predicted zone of deposition was based on estimates provided in a previous study (Franzin *et al*., 1979). Liver and skeletal muscle from white sucker (*Catostomus commersoni*) and northern pike (*Esox lucius*) were analyzed for arsenic, copper, cadmium, mercury, lead, selenium, and zinc. Thirteen lakes were sampled. Five lakes were from within an 8 km radius of the smelter (Flin Flon lakes); four lakes from 23 to 43 km east of the smelter (Manitoba lakes), and four lakes from 68 to 84 km northwest of the smelter (Saskatchewan lakes). Lake water from which fish were collected were analyzed for ionic composition. The survey was intended to evaluate the impact of a number of factors on concentrations in fish tissue including: lake water chemistry, distance from smelter, direction of prevailing winds, as well as species, sex, and age of fish. The potential impact of the installation of the taller stack in 1974 was also considered. Sediment core samples were taken from the sampled lakes in 1985 to assess the metal loadings and the impact of emission control measures over time.

Comments: Raw data are provided within this report however there is no interpretation or discussion of the data. The results of this study are discussed in Harrison and Klaverkamp (1990). This study did not measure metals in surface water; therefore, uptake factors cannot be derived. Sediment profiles (concentrations in µg/g) are available for copper, cadmium, mercury, selenium, and zinc from 0 to 25 cm. Mean sediment concentrations are available for each chemical for each lake. Mean concentrations are also provided for concentrations of metals in liver and muscle samples.

Other Relevant Information: Up until 1974, the base-metal smelter released emissions through two stacks measuring 53 and 69 metres in height. In 1974, a larger stack (250 m) was built to replace one of these shorter stacks. Emission controls installed in 1982 resulted in a reduction in particulate emissions by 85% (Fraser, 1983). Numerous studies have indicated that elevated concentrations of metals occur in water, sediment, and macrophytes sampled from lakes within the Flin Flon area (Van Loon and Beamish, 1977; Jackson, 1978; McFarlane and Franzin, 1978; McFarlane *et al*., 1979; Franzin and McFarlane, 1980; 1981).

Metal Contamination in Liver and Muscle of Northern Pike (*Esox lucius*) and White Sucker (*Catostomus commersoni*) and in Sediments from Lakes near the Smelter at Flin Flon, Manitoba.
S.E. Harrison and J.F. Klaverkamp. 1990. Environmental Toxicology and Chemistry. Vol. 9, pp.941- 956.

Objective: To determine if metal concentrations in fish sampled from lakes surrounding the smelter can be predicted based on metal concentrations in sediments or from limnological variables. In addition, metal concentrations in sediment cores were used to evaluate the estimate of the area significantly impacted by the deposition of emissions from the smelter.

Summary: This paper was based on the results of the sampling data provided by Harrison *et al*. (1989) in which 13 lakes, located at distances of 4.5 to 84 km from the smelter, were surveyed. Liver and muscle samples were taken from northern pike and white sucker in 1982 and were analyzed for arsenic, copper, cadmium, mercury, selenium, lead, and zinc. Sediment cores were also collected and analyzed for copper, cadmium, mercury, selenium, and zinc in 1985 (three years after significant reductions in smelter emissions). Surface water samples were not taken because metal contamination within aquatic ecosystems is generally more accurately reflected in sediment composition. It was believed that measurements of metals in sediments would be a better predictor of contamination in biological tissues than surface water would be.

Five lakes were from within an 8 km radius of the smelter (Flin Flon lakes); four lakes from 23 to 43 km east of the smelter (Manitoba lakes), and four lakes from 68 to 84 km northwest of the smelter (Saskatchewan lakes). These lakes were chosen to allow for a comparison of highly contaminated lakes (Flin Flon lakes), moderately contaminated lakes (Manitoba lakes), and slightly contaminated lakes (Saskatchewan lakes). Since winds are predominately from the northwest in Flin Flon, the Saskatchewan lakes were considered to be upwind, whereas the Manitoba lakes were downwind of the smelter. Concentrations of metals in within the top 2 cm of sediments were highest in the Flin Flon lakes, followed by the Manitoba lakes, and the Saskatchewan lakes. The average concentrations of metals in each lake, based on four cores taken from each lake, are summarized in Table A-14.

Table A-14 Summary of Mean Concentrations of Metals within the Top 2 cm of Sediments (µg/g d.w)

Group	*Lake*	*Distance (km)*	*Zinc*	*Copper*	*Cadmium*	*Mercury*	*Selenium*
Flin Flon	Hamell	4.5	8,408	2,775	56	3.27	11.1
	Douglas	5	12,625	1,900	60	3.77	12.6
	Phantom	5.4	6,988	1,385	36	9.22	4.5
	Cliff	5.6	5,950	1,278	21	6.39	4.0
	Meridian	7.6	2,858	568	15	2.69	3.4
Manitoba	Cleaver	23	1,238	198	7	1.30	2.5
	Naosap Mud	27	282	49	2	0.10	1.4
	Kotyk	30	507	76	3	0.35	2.4
	Nekik	43	170	34	<1	0.09	1.0
Saskatchewan	1	68	118	44	<1	0.11	0.9
	2	74	175	41	<1	0.14	1.3
	3	83	46	13	<1	0.03	0.2
	4	84	142	57	<1	0.22	0.9

Based on the depth profiles of metal concentrations in sediments, there is evidence to indicate that elevated concentrations in surface sediments can be attributed to smelter emissions. Assuming a vertical sedimentation rate of 1.2 mm per year (Johnson, 1987), the increased metal concentrations observed at depths of 8 to 10 cm correspond to the start of the smelting operations in 1930. Given that these lakes do not receive liquid effluent from the smelter and that they are over 400 km away from any major industrial complexes, there are no other significant sources of metals other than the deposition of smelter emissions.

The results of the sediment sampling indicate that the area receiving significant deposition of metals is likely much smaller than originally estimated by Franzin *et al*. (1979). Concentrations of metals in surface sediments of Saskatchewan lakes (68 to 84 km from the smelter) were equal to or less than lakes located in Ontario removed from significant anthropogenic sources.

Based on the ratio of surface sediment to background concentrations of metals in sediments, it appears that the limit of deposition to the east was approximately 43 km as indicated by analysis of sediments in Nekik Lake. A study completed by Zoltai (1988) found that elevated levels of metals in peat occurred in an elliptical pattern surrounding the smelter stretching to the southeast up to a distance of 110 km.

Generally, concentrations of most metals were found to be highest in the liver of fish from Flin Flon lakes. While concentrations of metals such as cadmium, copper, selenium, and zinc were higher in the liver of fish from Flin Flon, relative to Saskatchewan, the opposite was true for mercury. Concentrations of mercury in the liver of both northern pike and white sucker were significantly higher in Saskatchewan lakes than in Flin Flon lakes. A similar pattern was observed in Sudbury, where concentrations of mercury in crayfish and perch were lower with increased proximity to the smelter. This was attributed to two factors. First, selenium has been reported to inhibit the accumulation of mercury by fish, therefore, increased concentrations of selenium in lakes closest to the smelter can have a significant impact on mercury accumulation. Secondly, Methylmercury represents the largest component of total mercury within the tissues of fish. It has been reported that elevated concentrations of copper, cadmium, and zinc in sediments reduces the methylation of mercury (Jackson, 1984). This is supported by the current study in which the highest concentrations of mercury in fish were associated with the lowest concentrations of copper, cadmium, selenium, and zinc in sediments.

Concentrations of metals in muscle tissue were not consistently higher in fish sampled from the Flin Flon lakes. Although concentrations of selenium were significantly higher in the muscle tissue of both pike and sucker in Flin Flon lakes, concentrations of mercury and copper were significantly higher in Saskatchewan lakes than in Flin Flon lakes. Concentrations of zinc in the muscle of white sucker were significantly higher in Flin Flon lakes relative to Saskatchewan lakes. Concentrations of cadmium in muscle tissue were below detection in all lakes with the exception of northern pike from Cliff lake. Concentrations of arsenic and lead were almost all below detection limits (Table A-15). Concentrations of lead and arsenic were below detection limits (<0.02 and <0.05 µg/g, respectively) in almost all lakes. Detectable concentrations of arsenic were generally only found in lakes closest to the smelter. Concentrations of metals in the muscle of northern pike and the liver of white sucker were not significantly correlated with concentrations in sediments. However, concentrations of selenium in the liver of northern pike were positively correlated with selenium in sediment.

Table A-15 Mean Concentrations of Metals in the Muscle Tissue of Northern Pike and White Sucker (ug/g w.w)

Group	***Species***	***Zinc***	***Copper***	***Cadmium***	***Mercury***	***Selenium***
Flin Flon	Northern Pike	5.6	0.16	<0.01	0.09	0.88
	White Sucker	5.5	0.22	<0.01	0.02	1.05
Manitoba	Northern Pike	5.1	0.12	<0.01	0.22	0.20
	White Sucker	3.0	0.25	<0.01	0.03	0.22
Saskatchewan	Northern Pike	5.7	0.22	<0.01	0.47	0.29
	White Sucker	3.5	0.34	<0.01	0.06	0.28

Compared to concentrations of metals measured in fish in a 1976 survey, concentrations in fish measured in 1982 were lower (Table A-16).

Table A-16 Concentrations of Metals (µg/g w.w) in the Liver of Northern Pike and White Sucker from Hamell and Cliff Lakes in 1976 and 1982						
	Hamell Lake			***Cliff Lake***		
	Cadmium	***Copper***	***Mercury***	***Cadmium***	***Copper***	***Mercury***
Northern Pike						
1976	1.3	45	0.11	1.6	22	0.15
1982	0.79	19.5	0.03	1.03	11.9	0.04
White Sucker						
1976	1.1			2.7		
1982	0.51			0.48		

Conclusions: The results of the study indicate that concentrations of metals found in fish from the area surrounding the smelter were similar to concentrations observed in fish from remote lakes from the Precambrian shield of Ontario, which have not been impacted by anthropogenic sources. Concentrations in fish tissues were generally not directly proportional to concentrations in sediments. Results were generally similar to those observed in Sudbury.

Other Relevant Information: McFarlane and Franzin (1980) measured concentrations of cadmium, copper and mercury in the liver of northern pike and white sucker taken from five lakes within 20 km of the smelter in Flin Flon in 1976. The results of this study indicated that there was no significant relationship between concentrations of metals in liver and concentrations in sediments, metal deposition to lakes, or any other environmental variables.

Ross-Schist Lake Limnological Survey 1994 Final Report.
Hudson's Bay Mining and Smelting Environment Department.

Objective: To measure physical, chemical and biological conditions within the Ross-Schist Lake system.

Summary: Ross Lake receives water from Flin Flon Creek and surface runoff from the surrounding area. Water drains from Ross Lake to the northwest arm of Schist Lake *via* Ross Creek. Schist Lake is a central basin composed of four elongated arms. Water from Schist Lake drains to Lake Athapapuskow *via* Schist Creek. In addition to chemical analysis of metals in sediments, surface water, and fish tissue, physical parameters such as secchi depth, temperature, dissolved oxygen, conductivity and pH were measured. The mean pH of Ross and Schist Lakes were 7.79 and 8.42, respectively.

Heavy metal analyses are presented as extractable values, whereas arsenic and mercury are presented as total values. The laboratory detection limits for cadmium, lead, and mercury were all above the Manitoba Surface Water Quality Criteria (MSWQC). Concentrations of zinc from both lakes exceeded the MSWQCs.

Table A-17 Surface Water Chemistry Data for Ross Lake (mg/L)				
Chemical	***# samples***	***Maximum***	***Mean***	***MSWQC***
Copper	9	<0.01	<0.01	0.02
Zinc	9	**1.14**	**0.95**	0.047
Iron	9	0.25	0.2	1.0
Cadmium	9	**<0.01**	**<0.01**	0.002
Lead	9	**<0.04**	**<0.04**	0.0077
Nickel	9	<0.01	<0.01	0.16
Mercury	4	**<0.0002**	**<0.0002**	0.000006
Arsenic	6	0.004	0.004	0.190
Hardness ($CaCO_3$)	9	942.2	839	-

Table A-18 Surface Water Chemistry Data for Schist Lake (mg/L)				
Chemical	***# samples***	***Maximum***	***Mean***	***MSWQC***
Copper	54	0.02	0.01	0.02
Zinc	54	**0.34**	**0.05**	0.047
Iron	54	0.16	0.04	1.0
Cadmium	54	**<0.01**	**<0.01**	0.002
Lead	54	**<0.04**	**<0.04**	0.0077
Nickel	54	<0.01	<0.01	0.16
Mercury	5	**<0.0002**	**<0.0002**	0.000006
Arsenic	54	0.002	0.002	0.190
Hardness ($CaCO_3$)	54	638	402	-

Sediment samples were collected using an Ekkman Box Corer to collect the top 5 cm. Manitoba conservation does not provide sediment quality criteria.

Table A-19 Sediment Chemistry Data for Ross Lake (µg/g)			
Chemical	***# samples***	***Maximum***	***Mean[a]***
Copper	9	20,300	11,231
Zinc	9	64,700	43,023
Iron (%)	9	5.7	4.36
Cadmium	9	769	364
Lead	9	385	273
Nickel	9	50.9	40
Mercury	9	179	35
Arsenic	9	316	201
Manganese	9	415.4	368

[a] Mean values reported do not appear to be correct. Values presented were recalculated based on raw data presented in the report.

Table A-20 Sediment Chemistry Data for Schist Lake (µg/g)			
Chemical	***# samples***	***Maximum***	***Mean***[a]
Copper	31	11,270	NA
Zinc	31	91,100	NA
Iron (%)	31	9	NA
Cadmium	31	480.6	NA
Lead	31	235	NA
Nickel	31	52.6	NA
Mercury	31	12	NA
Arsenic	31	596	NA
Manganese	31	3,540	NA

[a] Mean values reported do not appear to be correct. Values presented were recalculated based on raw data presented in the report.

Fish samples were collected in July/August, 1994 and in October, 1994 using gill nets. Individual specimens were analyzed for metals in muscle tissue and liver tissue when sufficient tissue was available. Homogenizing of samples occurred when necessary. A total of 68 specimens were captured. Concentrations in fish from the northwest arm of Schist Lake did not exceed the Industry Services Branch of Manitoba Guidelines (1992). *Note, the report does not specify if concentrations are weight or dry weight.

TableA-21 Concentrations of Metals in the Tissues of Fish from Schist Lake Sampled in August 1994 (µg/g)										
Species	***Tissue***	***Parameter***	***Cu***	***Zn***	***Fe***	***Pb***	***Cd***	***Ni***	***Hg***	***As***
Northern Pike (n=5)										
	Muscle	Mean	1.0	8.5	7.5	0.3	<0.1	1.0	0.047	0.046
		Max	2.7	12.1	17.8	0.5	<0.1	3.6	0.078	0.098
	Liver	Mean	22.1	39.6	83.9	<0.3	<0.1	<0.2	0.056	0.029
		Max	28.9	51.2	135.4	<0.3	<0.1	<0.2	0.093	0.068
Walleye (n=1)										
	Muscle	Mean	-	-	-	-	-	-	-	-
		Max	0.6	6.0	6.8	<0.3	<0.1	0.5	0.064	0.065
	Liver	Mean	-	-	-	-	-	-	-	-
		Max	7.4	21.1	90.3	<0.3	0.5	<0.2	0.04	0.11
Cisco (muscle n=12, liver n=6)										
	Muscle	Mean	0.8	9.7	7.5	<0.3	<0.1	0.2	0.031	0.04
		Max	1.1	23.9	10.8	<0.3	<0.1	0.4	0.078	0.08
	Liver	Mean	6.9	18	98.8	<0.3	0.2	<0.2	0.148	0.140
		Max	12.6	34.2	151.3	<0.3	0.3	<0.2	0.690	0.194
Lake Whitefish (muscle n=2, liver n=1)										
	Muscle	Mean	0.5	6.1	4.5	0.4	<0.1	<0.2	0.026	0.042
		Max	0.5	6.2	4.7	0.4	<0.1	<0.2	0.026	0.063
	Liver	Mean	-	-	-	-	-	-	-	-
		Max	7.1	22.1	80.4	<0.3	0.4	<0.2	0.330	0.119

Table A-22 Concentrations of Metals in the Tissues of Fish from Schist Lake Sampled in October 1994 (µg/g)

Species	Tissue	Parameter	Cu	Zn	Fe	Pb	Cd	Ni	Hg	As
Northern Pike (n=19)										
	Muscle	Mean	0.8	5.9	5.2	0.3	0.1	0.2	0.028	0.020
		Max	1.3	8.6	7.7	0.5	0.3	0.3	0.074	0.028
	Liver	Mean	10	38.5	29	<0.3	0.1	0.2	0.018	0.019
		Max	20.2	59	71.1	<0.3	0.6	0.5	0.028	0.035
White Sucker (muscle n=4, liver n=2)										
	Muscle	Mean	0.7	4.9	4.5	0.3	0.2	<0.2	0.011	0.025
		Max	0.8	5.7	5.0	0.4	0.2	<0.2	0.015	0.039
	Liver	Mean	7.9	32.7	33	0.5	0.3	0.3	0.034	0.053
		Max	9.4	34.1	37.3	0.7	0.3	0.3	0.037	0.067
Cisco (muscle n=21, liver n=10)										
	Muscle	Mean	0.5	5.4	5.5	0.3	0.2	0.2	0.012	0.031
		Max	0.7	7.2	8.0	0.4	0.4	0.3	0.02	0.045
	Liver	Mean	4	21.7	130.1	0.4	0.3	0.2	0.018	0.068
		Max	15.7	44.5	384.4	1.0	0.7	0.3	0.020	0.094
Lake Whitefish (muscle n=4, liver n=2)										
	Muscle	Mean	0.5	5.4	4.4	0.3	0.1	0.2	0.011	0.029
		Max	0.6	6.0	5.9	0.4	0.2	0.3	0.015	0.040
	Liver	Mean	5.9	27.3	38.5	0.5	0.6	0.4	0.056	0.044
		Max	6.4	28	41.6	0.7	0.7	0.4	0.058	0.042

A-6.0 SURFACE WATER DATA

Dynamic Coupled Metal Transport-Speciation Model: Application to Assess a Zinc-Contaminated Lake.
S.P. Bhavsar, M.L. Diamond, N. Gandhi, and J. Nilsen. 2004. Environmental Toxicology and Chemistry, Vol. 23, No. 10, pp. 2410-2420.

Objective: To apply the coupled metal transport and speciation/complexation model (TRANSPEC) to examine seasonal variations in zinc dynamics and to predict long-term zinc concentrations in the water column and sediment of Ross Lake.

Summary: Ross Lake is a relatively shallow lake comprised of two basins. The north basin receives treated alkaline effluent overflow through Flin Flon Creek from tailings ponds. Water flows from the north basin to the south basin through a channel and eventually flows to Ross Creek to downstream lakes. Although current loadings of zinc to Ross Lake are estimated to be between 25 and 50 kg/day, historic levels from the 1930's to the 1950's were approximately 1,000 to 1,250 kg/day. Ross Lake also received an unknown amount of raw sewage from the 1930's to the early 1950's. Average zinc concentrations in sediment cores from the north basin were 40,000 µg/g in the top 5 cm and 100,000 µg/g in the following 20 cm. The highest concentration of 150,000 µg/g was found at 18 cm. Within the south basin, concentrations in the top 5 cm were 20,000 to 70,000 µg/g in the following 20 cm. The highest concentration of 110,000 µg/g was found at15 cm. The profile for copper was similar to that observed for zinc. Concentrations of zinc in the water column varied seasonally with a minimum of 0.4 to 0.5 mg/L in winter (December to February) and a maximum of 1.2 to 1.3 mg/L in fall (September to November). Within the water column, 80 to 90% of zinc is in the dissolved phase. During the fall season when surface sediments are oxic, the dissolution of ZnS increases pore water concentrations and results in an increase in diffusive flux from sediment to water. This flux is reduced somewhat by the binding of zinc in pore water to the colloidal phase that has a lower mass transfer coefficient.

Development of a Coupled Metal Speciation-Fate Model for Surface Aquatic Systems.
S.P. Bhavsar, M.L. Diamond, L.J. Evans, N. Gandhi, J. Nilsen, and P. Antunes. 2004. Environmental Toxicology and Chemistry, Vol. 23, No. 6, pp. 1376- 1385.

Objective: To report on the development of a coupled chemistry fate model (TRANSPEC) for surface water that uses the multispecies fugacity/aquivalence concept to predict fate.

Summary: The model was used to predict the fate of zinc in Ross Lake. Findings indicate that Ross Lake has shifted from being a net sink to a source of zinc despite reduced organic loadings from sewage and decreased loadings from mine tailings. Remobilization of zinc from sediments is causing increased metal concentrations in lake water. During the summer months when conditions in the surficial sediments are anoxic, there is a net water-to-sediment diffusion of zinc. However, in fall, when conditions in surficial sediments are oxic, this process is reversed and more soluble forms of zinc exist.

Metal Mining Environmental Effects Monitoring. FFTIS and Trout Lake Mine Initial Monitoring Program. Final Report.
Stantec Consulting Ltd. June 2005.

Objectives: The EEM was completed to evaluate the effects of mine effluent on fish, fish habitat and the use of fisheries resources.

Information Relevant to the HHRA: Surface water samples were collected from reference and exposure areas associated with the Flin Flon tailings impoundment system (FFTIS) discharge (the North Weir) and the Trout Lake mine discharge, both of which discharge into Flin Flon Creek. Maximum surface water concentrations from exposure areas (E) (at or downstream of the discharge areas) and reference areas (R) (similar characteristics to the exposure areas but unaffected by the discharge) are presented in Table A-23. Samples were collected in September 2004.

Table A-23 Maximum Surface Water Concentrations Measured in Areas Affected by HBMS Discharge and Selected Reference Areas (µg/L)

Chemical	*Beaver Dam Creek (R)*	*North Weir (E)*	*Flin Flon Creek (R)*	*Flin Flon Creek (E)*	*Ross Creek (E)*	*Phantom Lake (R)*	*Schist Lake (E)*
Aluminum	216	81	101	90	762	87	84
Arsenic	4.4	3.1	3.9	4	5.8	7.9	3.4
Cadmium	2.15	1.19	1.88	2.18	7.9	0.2	1.2
Copper	242	80	89	79	237	9	86
Iron	360	640	640	700	1440	150	800
Mercury	<0.05	<0.05	<0.05	<0.05	0.1	0.06	0.05
Molybdenum	0.3	10.7	9.7	9	6.3	7	11
Nickel	2	7	7	8	5	3	7
Lead	5.5	2.2	2.8	2.4	15.6	3.2	2.2
Zinc	610	330	390	480	920	140	280

Fractionation and Aqueous Speciation of Zinc in a Lake Polluted by Mining Activities, Flin Flon, Canada.
L.J. Evans. 2000. Water, Air, and Soil Pollution 122: 299-316.

Objective: To analyze the content of heavy metals in surface water and sediments in Ross Lake and Flin Flon Creek and to determine the forms of zinc found in sediments.

Information Relevant to the HHRA: Although previous studies have indicated the presence of metals at elevated concentrations primarily related to the deposition of smelter emissions, levels in Ross Lake are more likely related to direct discharge from the tailings ponds. As part of the current study, surface water and sediments were sampled in April, June, July, and September of 1996 at five sites in Ross Lake and one site in Flin Flon Creek.

Table A-24 Concentrations of Metals (µg/L) Found in Surface Waters of Ross Lake and Flin Flon Creek[a]

Chemical	*Ross Lake*	*Flin Flon Creek*
Cadmium	10.4	3.88
Cobalt	1.71	1.47
Chromium	0.86	0.77
Copper	185	30.5
Iron	712	1350
Manganese	80.4	104
Molybdenum	5.26	5.90
Nickel	23.1	29.5
Lead	12.3	2.56
Vanadium	3.06	3.24
Zinc	928	459

[a] Concentrations represent the higher of the averages for samples taken in April, June, July and September.

Analysis of metals in sediments indicated that zinc was primarily in the form of zinc sulphide.

Ross-Schist Lake Limnological Survey 1994 Final Report.
Hudson's Bay Mining and Smelting Environment Department.

Objective: To measure physical, chemical and biological conditions within the Ross-Schist Lake system.

Summary: Ross Lake receives water from Flin Flon Creek and surface runoff from the surrounding area. Water drains from Ross Lake to the northwest arm of Schist Lake *via* Ross Creek. Schist Lake is a central basin composed of four elongated arms. Water from Schist Lake drains to Lake Athapapuskow *via* Schist Creek. In addition to chemical analysis of metals in sediments, surface water, and fish tissue, physical parameters such as secchi depth, temperature, dissolved oxygen, conductivity and pH were measured. The mean pH of Ross and Schist Lakes were 7.79 and 8.42, respectively.

Heavy metal analyses are presented as extractable values, whereas arsenic and mercury are presented as total values. The laboratory detection limits for cadmium, lead, and mercury were all above the Manitoba Surface Water Quality Criteria (MSWQC). Concentrations of zinc from both lakes exceeded the MSWQCs.

Table A-25 Surface Water Chemistry Data for Ross Lake (mg/L)				
Chemical	***# samples***	***Maximum***	***Mean***	***MSWQC***
Copper	9	<0.01	<0.01	0.02
Zinc	9	**1.14**	**0.95**	0.047
Iron	9	0.25	0.2	1.0
Cadmium	9	**<0.01**	**<0.01**	0.002
Lead	9	**<0.04**	**<0.04**	0.0077
Nickel	9	<0.01	<0.01	0.16
Mercury	4	**<0.0002**	**<0.0002**	0.000006
Arsenic	6	0.004	0.004	0.190
Hardness ($CaCO_3$)	9	942.2	839	-

Table A-26 Surface Water Chemistry Data for Schist Lake (mg/L)				
Chemical	***# samples***	***Maximum***	***Mean***	***MSWQC***
Copper	54	0.02	0.01	0.02
Zinc	54	**0.34**	**0.05**	0.047
Iron	54	0.16	0.04	1.0
Cadmium	54	**<0.01**	**<0.01**	0.002
Lead	54	**<0.04**	**<0.04**	0.0077
Nickel	54	<0.01	<0.01	0.16
Mercury	5	**<0.0002**	**<0.0002**	0.000006
Arsenic	54	0.002	0.002	0.190
Hardness ($CaCO_3$)	54	638	402	-

Douglas Lake Surface Water Data (1993)
Saskatchewan Environment, Environmental Protection Branch
Provided by George Bihun, Environmental Officer

Summary: Saskatchewan Environment provided a spreadsheet with various water chemistry data. Concentrations of metals are provided for Douglas Lake opposite the Creighton WTP. The most recent data are from August 1993 as summarized in the following Table. Only concentrations of arsenic and zinc were found above the laboratory detection limit.

Table A-27 Concentrations of Total Metals in Surface Water of Douglas Lake in August 1993	
Chemical	***Concentration (µg/L total)***
Arsenic	8
Cadmium	<1
Copper	<1
Lead	<5
Molybdenum	<5
Selenium	<1
Silver	<1
Zinc	82

A-7.0 BLUEBERRY DATA

Monitoring for Mercury and Lead in Blueberry Plants (*Vaccinium myrtilloides* (*Michx*)) of the Flin Flon area, 1980 and 1981.
D.B. McEachern and S.F. Phillips, Terrestrial Standards and Studies, Environmental Management Services Branch, Department of Environment and Workplace Safety and Health. Report 83-12. December, 1983

Objective: To determine the levels of mercury (Hg) and lead (Pb) contamination in blueberries and soil in the primary areas of pollution dispersal from the Hudson Bay Mining and Smelting (HBMS) complex.

Summary: This study involved the sampling of blueberry components (berries: washed and unwashed, leaves, stems, roots) and the surface organic soil layer from 11 sites up to a 40 km distance from the HBMS complex in 1980 and 1981. The sampling sites were located to the northeast and southeast of the smelter. These were selected based on the predominant wind direction (towards the east and southeast) and accessibility to berry pickers. Data was presented in both wet weight (ww) and dry weight (dw), but the paper focused on the wet weight (dw standardized to 70% water content: ww = dw*0.3) on the basis that this form is eaten.

Data suggested that Hg does not accumulate in blueberry fruit. The mercury content of the blueberries ranged from 0.02 to 0.04 µg/g (wet weight, washed and unwashed) and did not exceed background levels (0.02 to <0.04 µg/g) (Table A-28), or the maximum acceptable dietary concentration established by the Canadian Food and Nutrition Board (0.05 µg/g). In 1980 and 1981, washed blueberry concentrations (dry weight) ranged from <0.02 to <0.1 µg/g and background ranged from <0.03 to <0.07 µg/g. Unwashed berry concentrations (dry weight) ranged from 0.06 to 0.13 µg/g and background concentrations ranged from 0.07 to 0.09 µg/g (Table A-28).

Table A-28 Mercury Concentrations (µg/g, wet and dry weight)[a] in Blueberries in Flin Flon Manitoba at select distances from the HBMS Complex

			Washed				*Unwashed*			
			1980		*1981*		*1980*		*1981*	
Dispersion Sector[b]	***Distance (km)***[c]	***Site No.***	***Dry***	***Wet***	***Dry***	***Wet***	***Dry***	***Wet***	***Dry***	***Wet***
N-NE	2	11	<0.02	<0.04	<0.09	<0.03	0.1	0.03	0.09	0.03
N-NE	4.6	8	<0.03	<0.04	<0.07	<0.02	0.11	0.03	0.06	0.02
N-NE	3.2	10	<0.05	<0.04	<0.08	<0.02	0.13	0.04	0.08	0.02
E-SE	3.7	9	<0.03	<0.03	<0.08	<0.02	0.1	0.03	0.08	0.02
E-SE	5.1	1	<0.02	<0.03	<0.07	<0.02	0.12	0.03	0.07	0.02
E-SE	8.9	2	<0.03	<0.04	<0.10	<0.03	0.12	0.03	0.1	0.03
E-SE	15.5	3	<0.02	<0.04	<0.06	<0.02	0.13	0.03	0.06	0.02
E-SE	38.9	4	<0.03	<0.04	<0.07	<0.02	0.09	0.03	0.07	0.02
SE-E	2.5	7	<0.04	<0.04	<0.08	<0.02	0.12	0.04	0.08	0.02
SE-E	5.8	5	<0.03	<0.04	<0.09	<0.03	0.11	0.03	0.09	0.02
SE-E	19.6	6	<0.02	<0.04	<0.06	<0.02	0.1	0.03	0.06	0.02

[a] Wet weight value is adjusted to 70% water content. Wet weight = dry weight x 0.30
[b] The wind direction followed a directional gradient with highest levels to the east and southeast
[c] Distance from the HBMS Complex

There were no significant differences between the samples in close proximity to the mining and smelting complex and the control (39 km SE), samples in the prevailing wind direction and those that were not, and washed compared to unwashed blueberries.

An exponential decline between distance from the smelter and Hg concentrations in the soil, leaves, stems, and roots suggested that the smelter was the source of Hg. The influence of the wind was demonstrated with an even stronger exponential relationship in the samples that lay in the prevailing wind direction. Concentrations were most elevated at sites within 5 km of the smelter, and were similar to background (Site 4) at sites beyond 15 km. Concentrations of Hg in soil exceeded levels found in blueberry components. No analysis was conducted in regards to the uptake of Hg from the soil by the blueberry components.

Levels of Pb in the blueberries ranged between 0.52 to 2 µg/g (wet weight), and exceeded the background levels (0.19 to 0.57µg/g wet weight) (Table A-29). In general, washed berries had lower levels of Pb than those unwashed, however, levels remained above background (Site 4). The blueberry Pb concentrations exceeded the average level of Pb in berries in Canada (0.05 µg/g). The Pb concentrations in the blueberries at the background site (Site 4) were close to the Canadian average (1/4 exceedance in dry weight concentrations). The study alluded to the WHO TDI for Pb (430µg/day), and the Canadian guideline for fresh fruit (7 µg/g) presently under review, but no conclusions were made in regards to whether consumption of the blueberries was safe. The data was forwarded to the Food Directorate of Health and Welfare Canada for further assessment in relation to dietary guidelines.

Table A-29 Lead Concentrations (µg/g, wet and dry weight)[a] in Blueberries in Flin Flon Manitoba at select distances from the HBMS Complex

			Washed				*Unwashed*			
			1980		*1981*		*1980*		*1981*	
Dispersion Sector[b]	*Distance (km)[c]*	*Site No.*	*Dry*	*Wet*	*Dry*	*Wet*	*Dry*	*Wet*	*Dry*	*Wet*
N-NE	2	11	2.3	0.69	4.3	1.29	3.4	1.02	7.7	2.31
N-NE	4.6	8	2.6	0.77	4.1	1.23	4.9	1.47	4.5	1.26
N-NE	3.2	10	1.6	0.49	-	2	3.5	1.31	4.9	1.48
E-SE	3.7	9	5	1.5	2.4	0.71	5	1.5	2.4	0.72
E-SE	5.1	1	4.5	1.35	1.8	0.54	5.2	1.57	3.9	1.18
E-SE	8.9	2	1.9	0.58	2.5	0.75	2.1	0.63	2.4	0.72
E-SE	15.5	3	1.8	0.54	2.3	0.69	2.1	0.6	2.1	0.63
E-SE	38.9	4	0.61	0.19	1.9	0.57	0.94	0.29	1.6	0.48
SE-E	2.5	7	1.8	0.66	2.4	0.72	2.7	0.81	2.3	0.7
SE-E	5.8	5	2.1	1.36	2.1	0.62	2.2	0.66	1.9	0.57
SE-E	19.6	6	1.7	0.52	1.9	0.57	1.7	0.51	2.1	0.63

[a] Wet weight value is adjusted to 70% water content. Wet weight = dry weight x 0.30
[b] The wind direction followed a directional gradient with highest levels to the east and southeast
[c] Distance from the HBMS Complex

Lead concentrations in the blueberry fruit were the lowest compared to the other components, and levels in the soil were the highest (soil>stem>roots>leaves>fruit). Authors speculated that the stem accumulated Pb through the leaves and roots (which absorbed Pb from soil). No analysis was conducted to verify these pathways.

A decline in Pb concentrations with distance occurred for all of the blueberry components. The most pronounced decline occurred in the samples located between 10 and 15 km, and declined to background levels beyond 15 km.

The possible risk to wildlife from grazing of the blueberry components was not assessed in this study. Overall, declining levels of Pb and Hg in blueberry components and soil implicated the smelter as a source of these chemicals. Hg did not accumulate in the blueberry fruit beyond acceptable levels. Pb did accumulate in blueberries, albeit at lower levels than found in other blueberry components. Washing the blue berries reduced Pb levels.

Comments:
The data was interpreted on an observational basis using tables and graphs. However, statistics were not performed to evaluate the significance of trends. For example, the exponential decay of metal levels with distance; wind as a significant a factor: difference between concentrations in predominant wind direction and not. The study mentioned the WHO TDI for lead, and that the Canadian TDI was under review. However, the study did not did not use the data to estimate whether the TDI was exceeded (using average levels in diet, or correcting for body weight).

Other Relevant Information:

- A reference is made to the average level of lead in Canadian berries (0.05 µg/g) from the Nutrition Foundation (1982);
- Raw data for washed and unwashed berries (wet and dry weight), leaves, stems, roots, and soil is presented (wet weight).This information could potentially be used to derive uptake factors; and,
- This study was conducted to as a follow-up to recommendations made in a previous study (Wotton, 1979) which reported elevated levels of Hg and Pb in blueberries from an area 2.5 km southeast of Flin Flon (Louis Lake Area).

A survey of Mercury and Lead in Vaccinium myrtilloides (Michx.) of the Flin Flon Area.
Wotton, D.L. 1979. Manitoba Department of Mines, Natural Resources and Environment, Environmental Research and Development Branch. Report 79-3: 17pp. 1979.

Objective: To investigate levels of mercury (Hg) and lead (Pb) in blueberry plants in the vicinity of the HBMS Complex.

Summary: Blueberry fruit and plant components (leaves, stems, roots, and surface soils) were sampled at nine locations at varying distances (2.5 to 38.1 km) from the HBMS Complex (herein referred to as the smelter). The majority of the sites (7) were located in the primary dispersal direction (S, SE). A sample site located 38.1 km SE of the smelter (Site 4) was considered to be a control site. Dry and wet weight concentrations were reported, but the report focused on the dry weight values in the discussion.

Dry weight concentrations of mercury in berries (0.02 to 0.17 µg/g) exceeded the acceptable dietary concentration published by Canadian Food and Nutrition Board (0.05µg/g) at five of the nine sampling locations (Table A-30). Concentrations were similar to those measured at two of the sites in a 1978 survey by the Canadian Wildlife Service. The sites with concentrations (dry weight) similar to background (0.02 µg/g, Site 4) were located 5.1 km E (Site 1), 3.7 km and 15.5 km SE (Site 3), and 14.6 km S (Site 6) of the smelter.

Table A-30	Mercury Concentrations (µg/g, wet and dry weight) in Blueberries in Flin Flon Manitoba at select distances from the Hudson Bay Mining and Smelting Complex				
Dispersion Sector [a]	***Distance (km)*** [b]	***Site No.***	***1979***		***1978*** [c]
			Dry	***Wet***	***Dry (unwashed)***
E	5.1	1	<0.02	<0.06	-
SE	8.9	2	0.08	0.02	-
SE	15.5	3	0.03	<0.02	-
SE	38.1	4	0.02	<0.02	0.02
S	5.8	5	0.12	0.03	-
S	14.6	6	0.05	<0.02	-
S	2.5	7	0.16	0.03	0.22
N	4.6	8	0.17	0.05	-
SE	3.7	9	0.04	<0.02	-

The Pb concentrations were reported in dry weight. There were no discernible differences in the concentrations of the washed and unwashed berries, with concentrations ranging from 1.18 to 2.12 µg/g, and from 1.16 to 2.43 µg/g, respectively (Table A-31). Concentrations were similar to those of background (<1.2 to <1.25µg/g). The Pb concentration measured in a 1978 survey at site 7 (7.0 µg/g) significantly exceeded the concentration reported in this study at the same site (1.23µg/g). The lead levels measured in this study did not exceed the maximum allowable concentration by the U.S. Food and Drug Administration (7 µg/g).

Table A-31	Lead Concentrations (µg/g, dry weight) in Blueberries in Flin Flon Manitoba at select distances from the HBMS Complex				
Dispersion Sector [a]	***Distance (km)*** [b]	***Site No.***	***Dry Weight***		
			1979		***1978*** [c]
			Washed	***Unwashed***	***Unwashed***
E	5.1	1	2.12	1.94	
SE	8.9	2	1.96	1.92	
SE	15.5	3	<1.21	1.16	
SE	38.1	4	<1.2	<1.25	N.D.
S	5.8	5	<1.21	1.97	
S	14.6	6	2.42	2.43	
S	2.5	7	<1.24	1.23	7
N	4.6	8	1.18	2.4	
SE	3.7	9	1.92	2.17	

[a] The wind direction followed a directional gradient with highest levels to the south and southeast
[b] Distance from the HBMS Complex
[c] Data reported by the Canadian Wildlife Service in a 1978 survey in Sites 4 and 7.

A general trend of declining Hg and Pb concentrations with increasing distance from the smelter was observed in the study, however, no statistically significant patterns were measured.

Concentrations of Twenty-Eight Elements in Fruiting Shrubs Downwind of the Smelter at Flin Flon, Manitoba
Shaw, G. 1981. Environmental Pollution (Series A) 25: 197-209.

Objective: To determine the extent of pollution from the smelter stack located in Flin Flon and its potential impact on wildlife by measuring the concentrations of 28 elements in three different plant species located at three locations ranging from 2.9 to 36.2 km southeast of the stack

Summary: The concentrations of 28 elements in the (unwashed) leaf, berry, and stem components of three shrubs common in the Flin Flon area were measured: blueberry (*Vaccinium myrtilloides),* manzanita *(arctostaphylos)*, and the bog cranberry (*Vaccinium vitis-idaea*). Measurements were taken in 1978 at three sites (Louis Lake, Mystic Creek, and Cranberry Portage) located 2.4 km, 26.5 km, and 36.2 km southeast of the smelter, respectively. Concentrations of As, Se, Hg, Pb, Cu, Fe and Zn were substantially greater at the site in closest proximity to the smelter (Louis Lake) compared to the two sites located beyond 25 km of the smelter (Mystic Creek and Cranberry Portage) (Table A-32). Statistical analyses showed good accuracy and precision of the data. Overall, the berries had the lowest elemental concentrations compared to the other plant components (leaves, stems).

Table A-32 Concentrations (µg/g, dry weight) of various elements in Blueberries in Flin Flon Manitoba at select distances from the Hudson Bay Mining and Smelting Complex

Chemical	*Sample Locations*[a]		
	Louis Lake (2.4km SE)	*Mystic Creek (26.5km SE)*	*Cranberry Portage (36.2km SE)*
Al	35	17	22
Ba	10.5	11.2	8.6
Be	ND	ND	ND
Cu	21.1	3.7	3.7
Fe	150	24.2	31.8
K	10,200	7,430	7,240
Mg	390	593	630
Mn	62.4	171	23.4
Na	300	ND	ND
P	1,080	920	1,000
Pb	7.0 - 7.26[b]	ND	ND
Hg	0.22	0.01	0.02
Sr	1.75	ND	ND
V	ND	23	17
Zn	24	ND	ND
Ag	0.5	ND	15
Cd	ND	ND	ND
Co	ND	ND	ND
Cr	3.8	1.7	ND
Mo	ND	ND	ND

Table A-32	Concentrations (µg/g, dry weight) of various elements in Blueberries in Flin Flon Manitoba at select distances from the Hudson Bay Mining and Smelting Complex		
Chemical	***Sample Locations[a]***		
	Louis Lake (2.4km SE)	***Mystic Creek (26.5km SE)***	***Cranberry Portage (36.2km SE)***
Ni	ND	ND	ND
Zr	ND	ND	ND
Ti	1.8	0.9	0.7
Th	ND	ND	ND
Si	1.8	ND	ND
As	1.74 - 2.0 [b]	0.31	0.16
Se	<0.2 - 0.22[b]	<0.03	0.07

* Highlighted rows indicate elements with greater concentrations at Louis Lake compared to Mystic Creek and Cranberry Portage.
[a] One sample was taken at each location
[b] Concentrations reported by two different labs (n=2)

Comments: Berries were unwashed, and concentrations are assumed to be reported in dry weight (no wet weight conversion was applied).

Manitoba Conservation Blueberry Study.
Manitoba Conservation 2000 (Unpublished).

Summary: Blueberry fruit samples were collected from 13 locations at distances ranging from 1.95 to 155 km from the HBMS smelter (Table A-33). Three replicates were taken at each site. All vegetation concentrations were based on analysis of a dried sample, and were washed. Mercury concentrations were all <0.01 µg/g. Lead concentrations ranged from <0.01 to 0.3 µg/g. Two of the sites reported concentrations ranging from 0.2 to 0.3µg/g. The first site was located 1.95 km NNE of HBMS smelter on the east side of railroad tracks. The second was located 2.51 km SSE of HBMS smelter on golf course road. The remaining eleven sites had concentrations <0.01µg/g. Four of these sites were located within 5 km of the smelter (2 ESE, NNE, NE) and seven were located up to 155 km from the HBMS smelter.

Table A-33	Concentrations of Lead and Mercury in Blueberries from the Flin Flon Area			
Location	***Date Sampled***	***Moisture %***	***Pb (ug/g)***	***Hg (ug/g)***
TQ0151	08/15/2000	84.1	< 0.1	< 0.01
TQ0151	08/15/2000	84.2	< 0.1	< 0.01
TQ0151	08/15/2000	84.7	< 0.1	< 0.01
TQ0152	08/15/2000	85.4	< 0.1	< 0.01
TQ0152	08/15/2000	82.5	< 0.1	< 0.01
TQ0152	08/15/2000	85.2	< 0.1	< 0.01
TQ0153	08/16/2000	83.4	< 0.1	< 0.01
TQ0153	08/16/2000	82	< 0.1	< 0.01
TQ0153	08/16/2000	83.3	< 0.1	< 0.01
TQ0154	08/16/2000	85	< 0.1	< 0.01
TQ0154	08/16/2000	77.8	< 0.1	< 0.01
TQ0154	08/16/2000	84	< 0.1	< 0.01
TQ0155	08/15/2000	84.2	< 0.1	< 0.01
TQ0155	08/15/2000	84.9	< 0.1	< 0.01
TQ0155	08/15/2000	83.8	< 0.1	< 0.01

Table A-33 Concentrations of Lead and Mercury in Blueberries from the Flin Flon Area

Location	Date Sampled	Moisture %	Pb (ug/g)	Hg (ug/g)
TQ0156	08/15/2000	82.9	< 0.1	< 0.01
TQ0156	08/15/2000	82.4	< 0.1	< 0.01
TQ0156	08/15/2000	81.5	< 0.1	< 0.01
TQ0157	08/15/2000	85.5	0.2	< 0.01
TQ0157	08/15/2000	83	0.3	< 0.01
TQ0157	08/15/2000	83.3	0.2	< 0.01
TQ0158	08/15/2000	83.6	< 0.1	< 0.01
TQ0158	08/15/2000	84	< 0.1	< 0.01
TQ0158	08/15/2000	83.5	< 0.1	< 0.01
TQ0159	08/15/2000	84.3	< 0.1	< 0.01
TQ0159	08/15/2000	84.2	< 0.1	< 0.01
TQ0159	08/15/2000	85.8	< 0.1	< 0.01
TQ0160	08/15/2000	83.9	< 0.1	< 0.01
TQ0160	08/15/2000	84.6	< 0.1	< 0.01
TQ0160	08/15/2000	83.2	< 0.1	< 0.01
TQ0161	08/15/2000	78.7	0.3	< 0.01
TQ0161	08/15/2000	85.9	0.2	< 0.01
TQ0161	08/15/2000	85.4	0.2	< 0.01
TQ0162	08/15/2000	81	< 0.1	< 0.01
TQ0162	08/15/2000	81.8	< 0.1	< 0.01
TQ0162	08/15/2000	79.6	< 0.1	< 0.01
TQ0163	08/17/2000	82.2	< 0.1	< 0.01
TQ0163	08/17/2000	82.5	< 0.1	< 0.01
TQ0163	08/17/2000	82.2	< 0.1	< 0.01