Arsenic Exposure Study for the Residents of Falconbridge

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Acknowledgements

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The Sudbury District Health Unit provided a thorough, professional review of the study methodology and process to ensure that it met the ethical standards of conducting research with communities. Many others also reviewed the methodology to provide suggestions for improvements. All of these reviews contributed to a solid study for the community.

Falconbridge Ltd. sponsored the study and provided the necessary resources to ensure that the study addressed the community's concerns.

Finally, we would like to express our deep appreciation to the many residents of Falconbridge and Hanmer who invited us in to their homes for interviews, provided samples for analysis, and expressed interest in the study. We hope you find that this study provides answers to some of the important questions you have asked.

Summary

Overview

This report documents the results of the Arsenic Exposure Study for residents of Falconbridge, a small community located within the City of Greater Sudbury, Ontario. Falconbridge Ltd. commissioned the study in response to community concerns with elevated levels of arsenic in soil on some residential properties in the town. Representatives from Falconbridge Ltd. and the research team worked with the Falconbridge Citizens' Committee to ensure that the study addressed the proper questions, and that the results would be useful to the community.

Community residents were consulted to identify primary concerns and to provide feedback on the objectives of the study. The research team then developed the study methodology to address two specific questions that were deemed to be most important by residents:

1) *Do Falconbridge residents have higher urinary arsenic levels than residents living in a comparison area with lower levels of arsenic in their soil?*

2) *What health risks relative to other communities are associated with the urinary arsenic levels of Falconbridge residents?*

For the present study, the research team developed a methodology that combined both the analysis of first morning void urine samples, and interviews that captured lifestyle information pertaining to potential arsenic exposure. The study was comparative in nature, meaning that the main questions above were addressed by comparing Falconbridge with a comparison community. Hanmer was selected as the comparison community as it is nearby and has similar characteristics to Falconbridge, but has significantly lower levels of arsenic in the soil. As well, the study used results from previous studies conducted in Ontario and Canada to make additional comparisons.

Discussions with the residents of Falconbridge began in the summer and fall of 2003. Dialogue continued as the study was designed during the winter of 2004. Sampling took place in September and early October, 2004.

Recruitment, sample collection and analysis

All current Falconbridge residents were invited to participate in the study. The research team also randomly recruited a similar number of families from the comparison community of Hanmer to participate.

The data collection process was identical in Falconbridge and the comparison community. Initially, potential participants were sent a letter indicating that a member of the study team would be dropping by their house to provide them a sample of the consent form, and to explain the study process. If they were willing to participate in the study, an appointment was schedule. At the appointment time, the study team walked the participants through the consent/assent forms in detail, had the participants sign them, and then conducted an in-home interview with the adults of the household. At the conclusion of the interview, each family was left a urine sampling kit with instructions. The study team then picked up the sample the following morning. Sample collection and interviewing occurred between early September and mid-October, 2004.

Samples were processed and shipped to London Health Sciences Trace Elements Laboratory, University of Western Ontario. All samples were analysed for creatinine, total arsenic and inorganic arsenic and its major metabolites (monomethylarsonic acid - MMA and dimethylarsinic acid – DMA).

Notification of individual urinary arsenic results

In December 2004, the research team physician notified participants of their individual results for inorganic and total urinary arsenic. Individuals who had samples that tested at or above the *a priori* screening level of 20μg/L for inorganic arsenic and 100μg/L for total arsenic (when adjusted for creatinine) were visited in their homes by the team physician to discuss their results. These individuals also received referrals for follow-up 24-hour testing under the supervision of their family physicians. It should be noted that these ranges do not refer to health effects, but rather are population distribution levels where 95% of a population would likely fall within these levels according to previous Canadian studies. All other participants who had levels within the ranges below the *a priori* determined screening levels were provided their results by mail with contact information for the team physician if they had any questions.

Study findings

Response rates

Falconbridge. 273 households were invited to participate in the study of which 148 (54%) agreed. Overall, information was collected for 393 participants in the interview portion of the study and, of these, 369 participants provided a urine sample.

Hanmer. Out of the 360 households approached, 129 (36%) agreed to participate in the study. Interviews captured information on 335 respondents and 321 participants provided urine samples.

Inorganic arsenic[1] levels

The distributions of urinary inorganic arsenic levels are relatively similar with positive skewing (predominance of lower levels) occurring in each community. Approximately 80% of the urine samples in each community had an inorganic arsenic level below 10μg/L. Approximately 2-3% of samples in each community were at or above 20μg/L. The average inorganic arsenic levels in urine samples were similar across communities. The arithmetic mean for Falconbridge was 7.11μg/L in comparison with 7.19μg/L in Hanmer. Also, the medians (the point at which 50% of measures fall above and 50% fall below) for each of the communities were the same: 5.99μg/L in both communities. Levels generally decreased with increasing age, with children ages 6-12 years with the highest average values compared to the other age groups.

Total arsenic levels

The distribution of total arsenic levels was similar for the two communities. The distribution was positively skewed with over 80% of the samples with levels below 20μg/L. Approximately 2-3% of samples in each community were at or above 100μg/L. In Falconbridge, there were two samples that are considered extreme outliers. These individuals, along with the others who were above 100μg/L were referred to consult their physicians for re-testing.

The central tendency measures of total arsenic in urine samples are similar across communities. The median for each of the communities was similar: 8.99μg/L in Falconbridge and 9.74μg/L in Hanmer. When the arithmetic mean was examined, it was found that the mean for Falconbridge was 21.24μg/L in comparison with 14.10μg/L in Hanmer. At least part of this difference can be attributed to the two extreme outliers that have more influence on the arithmetic mean as a measure of central tendency in comparison to their impact on measures such as the median. Similar to the inorganic levels, the total levels generally decreased with age, with children ages 6-12 years with the highest average values compared to the other age groups.

Comparisons with other studies

The Falconbridge and Hanmer levels of inorganic arsenic were similar to other recent studies. The reader should be aware that not all of the studies have necessarily used the same analytic procedures, or collection procedures, and, as a result, some proportion of difference is likely due to the differences in methodology. It is impossible to determine to what extent the small differences that are observed are as a result of true differences in levels, or differences in collection and analyses, or characteristics of participants (e.g., sex, age, etc.).

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[1] Throughout the report, we use the term "inorganic arsenic" to refer to the sum of the inorganic species As3+ and As5+ and the major metabolites of inorganic arsenic, namely monomethylarsonic acid (MMA) and dimethylarsinic acid (DMA).

Comparison with Health Canada models

The research team also compared the results with the estimated typical daily intake models for inorganic arsenic that have been developed by Health Canada. The median levels measured in Falconbridge are all within the lower portions of the estimated ranges of intake for the average daily intake for Canadians.

Discussion

The study was designed to answer two main research questions. The research team provided answers to each question based on the results from the study.

Do Falconbridge residents have higher urinary arsenic levels than residents living in a comparison area with lower levels of arsenic in their soil?

No. Falconbridge residents' urinary arsenic levels were very similar to those in the comparison community of Hanmer. With respect to ***inorganic arsenic***, the type of arsenic most closely associated with health effects, the average levels in each community were nearly identical. Falconbridge residents had a mean level of 7.1μg/L and a median level of 6.0μg/L in comparison with Hanmer residents who had a mean level of 7.2μg/L and a median level of 6.0μg/L. Approximately 80% of the urine samples in each community had an inorganic arsenic level below 10μg/L, and approximately 2-3% of samples in each community were at or above 20μg/L. Between the communities, there were no statistical differences overall or by various age groups.

With respect to ***total arsenic*** (both organic and inorganic forms), the communities again demonstrated similar distributions of urinary arsenic levels. The median level among Falconbridge residents was 8.9μg/L compared to 9.7μg/L for Hanmer residents. The mean levels were 21.2μg/L for Falconbridge residents compared to 14.1μg/L for Hanmer residents. There were two extreme outliers measured in the Falconbridge community that had a strong impact on the mean, but limited impact on the median as a measure of central tendency. The distribution is positively skewed with over 80% of the samples with levels below 20μg/L. Approximately 2-3% of samples in each community were at or above 100μg/L. Statistical comparisons (non-parametric – Mann Whtney U) that were less influenced by extreme outliers indicated that there was not a statistically significant difference between the two communities. The statistical comparisons that tested the difference between means (independent t-test) found that Falconbridge residents had statistically higher average levels of total arsenic when compared to Hanmer residents.

In summary, for the form of arsenic that is most generally accepted to be a health concern for humans (inorganic arsenic), the two communities have nearly identical average levels. When we examine total arsenic levels that include both inorganic arsenic levels and organic arsenic levels (generally obtained through diet), we found that Falconbridge residents have similar levels with the exception of two extreme outliers.

What health risks relative to other communities are associated with the urinary arsenic levels of Falconbridge residents?

Falconbridge and Hanmer residents on average are within the typical daily intake of arsenic by Canadians, and therefore are not at any increased risk from arsenic exposure as compared to other Canadians in general.

Health risks associated with urinary arsenic levels for Falconbridge residents would be similar to those in the comparison community of Hanmer. The median levels in Falconbridge are within the lower portion of the range estimated for typical daily intake of arsenic by Canadians (Health Canada).

1.0 Introduction

This report documents the results of the Arsenic Exposure Study for residents of Falconbridge, a small community located within the City of Greater Sudbury, Ontario. Falconbridge Ltd. commissioned the study in the fall of 2003 in response to community concerns with elevated levels of arsenic in soil on some residential properties in the town. Representatives from Falconbridge Ltd. and the research team worked with the Falconbridge Citizens' Committee to ensure that the study addressed the proper questions, and that the results would be useful to the community.

Once community residents were consulted to identify primary concerns and to provide feedback on the objectives of the study, the research team developed the study methodology to address two specific questions that were deemed to be most important by residents:

1) *Do Falconbridge residents have higher urinary arsenic levels than residents living in a comparison area with lower levels of arsenic in their soil?*

2) *What health risks relative to other communities are associated with the urinary arsenic levels of Falconbridge residents?*

For the present study, the research team developed a methodology that combined both the analysis of first morning void urine samples, and interviews that captured data pertaining to potential arsenic exposure. This methodology is explained in greater detail in the following sections.

1.1 Report structure

The report has six main sections. These include:

- *Section 1.0* – the introduction, study background and a general overview on arsenic exposure;
- *Section 2.0* – the study approach, methodology and process are described in this section.
- *Section 3.0* – the descriptive results from the study including a brief community profile of key socio-demographic variables.
- *Section 4.0* - the distributions and comparative analyses for the urinary arsenic levels. The urinary arsenic levels found in Falconbridge are compared with those

from the comparison community of Hanmer, as well as those from other Canadian communities and typical Canadian intakes.

- *Section 5.0* – the regression models used to find associations between urinary arsenic levels and various variables such as diet and smoking status.

- *Section 6.0* –the discussion of results according to the two study questions posed, and a discussion of challenges and limitations.

1.2 Background on communities

The study community of Falconbridge and the comparison community of Hanmer are part of the City of Greater Sudbury, which serves as the regional capital of northeastern Ontario. The City of Greater Sudbury was formed on January 1, 2001. The new City represents the amalgamation of the towns and cities that comprised the former Regional Municipality of Sudbury, as well as several unincorporated townships. Sudbury is located 390 kilometers north of Toronto, 290 kilometers east of Sault Ste. Marie, and 480 kilometers west of Ottawa.

1.2.1 Falconbridge

The community of Falconbridge is located approximately 20 kilometers northeast of the Sudbury city core. Falconbridge is comprised of approximately 250 households with 700 residents. Situated on the eastern perimeter of the community are the smelting operations of Falconbridge Ltd. Although the current population of the community has a variety of employment characteristics, the community initially developed as a residential site for Falconbridge Ltd.'s employees and their families.

1.2.1.1 Background on Falconbridge Ltd. mining and smelter activities

Falconbridge Ltd. has been mining nickel-copper ores in the Sudbury region of Ontario since 1928. The operations currently employ approximately 1500 people and consist of underground mines, a mill and a smelter. These facilities are spread throughout the 90-kilometre-wide oval-shaped geological formation known as the Sudbury Basin. Nickel and copper are the primary metals but Falconbridge Ltd. also produces cobalt and precious metals.[2]

A publication[3] released in 1992 indicated that the history of the smelting operations can be divided into the following four phases:

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[2] http://www.falconbridge.ca ,2004
[3] J.F. Jackson, 1992. <u>The Evolution of the Falconbridge Smelter</u>. Falconbridge Limited, Sudbury Division.

Phase 1: Ore Smelting (1930-1933)
The Falconbridge Smelter initially consisted of a single blast furnace and two converters. The smelter feed was high-grade nickel copper ore from which some barren rock had been removed by hand picking. The mine ore had been crushed into fine and coarse fractions. The coarse ore was smelted in a blast furnace along with solidified converter slag, limestone and coke. The fine ore fraction was fed to the converter where it was melted. This mode of operation continued until 1933 with nickel production increasing from 3 million to 6 million pounds per year.

Phase 2: Ore-Sintering Smelting (1933-1954)
In 1933, the concentrator was built to treat low-grade ore and a Sinter Plant was erected to treat concentrates. The "Old Smelter" treated furnace ore, converter ore and sintered concentrates until 1954. Mine production increased and the feed to the Smelter gradually changed from all ore to mostly concentrate. The original blast furnace was enlarged and two more furnaces added. The two existing converters were moved, then enlarged and finally two more were added. Over this period the nickel production rose to 50 million pounds per year.

Phase 3: Sintering Smelting (1954-1978)
In this phase the "New Smelter" was constructed, consisting of a new converter aisle with a new blast furnace and two converters. The "Old Smelter" was operated in conjunction as required to maintain production. A second blast furnace and two converters were added over the period. Nickel production continued to increase to an output of 97 million pounds of nickel in 1971. This increase in output was achieved by continued change from smelting ore to smelting essentially all concentrate.

Phase 4: Electric Smelting (1978 to Present)
The current phase of the smelter was the construction and start up of the Smelter Environmental Improvement Project (SEIP). This included the installation of two slurry fed bed roasters, two electric furnaces and an Acid Plant to treat the roaster gases. The converter aisle in the New Smelter was retained and the blast furnaces and the Sinter Plant shut down. The objectives of the SEIP were to reduce sulphur dioxide emissions, reduce operating costs, improve metal recoveries and improve working conditions.

1.2.2 Hanmer

The comparison community of Hanmer is located approximately 20 kilometers north of the Sudbury city core and 15 km northwest of Falconbridge. The municipality of Hanmer is situated in a geographic area referred to as Valley East. Valley East has approximately 25 000 residents and 8 000 households[4]. Hanmer's population accounts for approximately 1/3 of the Valley East population. Valley East was traditionally an agricultural community and in recent years has relied increasingly on mining activity in

[4] City of Valley East Economic Development Department (2000) Valley East Community Profile 2000.

the Greater Sudbury area for employment[5]. The study team found no reported history of mining or smelting activity directly in Hanmer.

1.2.3 Sudbury Soils Study

The Sudbury Soils Study (SSS) is a large-scale environmental study that is currently underway in the Sudbury area. The present health study is not a planned component of the SSS, however, it is anticipated that the results will inform the SSS with respect to the assessment of arsenic exposure commitment in the two communities studied.

In 2001, the Ontario Ministry of the Environment (MOE) released a report that identified the concentrations of nickel, cobalt, copper and arsenic exceeded the generic MOE soil quality guidelines. Under Ontario legislation, this triggers the need for more detailed study. Therefore, the MOE made two recommendations:

- That a more detailed soil study be undertaken to fill data gaps, and
- That a human health and ecological risk assessment be undertaken.

Both Inco Ltd. and Falconbridge Ltd. voluntarily accepted the recommendations and began working together to establish what is commonly referred to as "The Sudbury Soils Study".

The mining companies partnered with four other major stakeholders in Sudbury to oversee the SSS. The community partners are Inco Ltd., Falconbridge Ltd., the MOE, the Sudbury & District Health Unit (SDHU), the City of Greater Sudbury, and Health Canada First Nations and Inuit Health Branch (FNIHB). These partners formed a Technical Committee to oversee the study. A Public Advisory Committee was also established to help address questions and concerns about the potential impact of elevated metal levels on the local environment and on human health. As people who live and work in Sudbury, the members of this partnership share these questions and concerns.

The MOE and the mining companies undertook a comprehensive soil sampling and analysis program in 2001. Approximately 8,000 soil samples were collected from urban and remote areas and analyzed for 20 elements. These data form the basis for the SSS.

Early in 2003, a consortium of consulting firms working together as the SARA (Sudbury Area Risk Assessment) Group was retained to undertake the risk assessment portion of the study. The main partners of the SARA Group are C. Wren & Associates Inc., Cantox Environmental Inc., RWDI, SGS Lakefield, and Goss Gilroy Inc. Some members of the consortium were also retained by Falconbridge Ltd. to conduct the present arsenic exposure study given their experience with previous similar studies.

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[5] City of Valley East Economic Development Department (2000) Valley East Community Profile 2000.

1.2.4 Environmental characteristics of Falconbridge and Hanmer

Given that the SSS is collecting, compiling and analyzing large amounts of environmental monitoring data, the research team for the current study was able to use some of the public information to determine the average levels of arsenic in the soil for both Falconbridge and the comparison community of Hanmer. Information on arsenic concentration in environmental media other than soil (i.e., vegetables, air, indoor dust) are being collected as part of the SSS. It is expected these data will be made available if further interpretation of the results of this study are required.

Soil

As demonstrated in Table 1.1 below, the average soil levels in Falconbridge were significantly higher than those measured in Hanmer ($p<0.05$; independent t-test). The arithmetic mean for arsenic soil level in Falconbridge was 78.54µg/g, while in Hanmer the average arsenic soil level was 3.70 µg/g. The maximum soil level measured in Falconbridge was 620µg/g in comparison with 25µg/g in Hanmer.

Table 1.1 – Arsenic soil levels in Falconbridge and Hanmer (µg/g)

	Falconbridge	Hanmer
Mean	78.54	3.70
Standard deviation	84.88	3.47
Number of samples	879	143
Minimum	2.5	2.5
Maximum	620	25

* includes all depths (0-5, 5-10, 10-20cm) and both originals and duplicates

Water

Most residents in both communities are on municipal water systems. These systems are monitored on a regular basis for levels of arsenic. The arsenic in distributed drinking water meets the 2004 Canadian drinking water guideline of 0.005 mg/L.[6]

1.3 Arsenic and health effects

Arsenic is a naturally occurring element in the earth's crust, and is found throughout the environment. It is usually found combined with other elements such as oxygen, chlorine, and sulphur. When arsenic is combined with carbon containing compounds, it is usually referred to as organic arsenic. However, when combined with other elements, it is referred to as inorganic arsenic.

[6] Canadian Drinking Water Guidelines. http://www.hc-sc.gc.ca/hecs-sesc/water/pdf/dwg/arsenic.pdf Ontario Drinking Water Objectives

While arsenic-containing substances, both organic and inorganic, are naturally occurring, some are human-made. Arsenic is released naturally from ore bodies; however, human activity accounts for a significant amount of arsenic contamination in the soil. In Ontario, many gold, silver, nickel, copper and zinc ore bodies contain arsenic. As a result, the areas with highest level of arsenic are found near the vicinity of mining and sintering operations. A report published by the Environmental Protection Branch of Environment Canada stated that at one time the largest air emissions of arsenic from human activities in Canada were the smelting and refining of copper and nickel, but changes in smelting processes since the early 1980s have reduced these sources[7].

1.3.1 Arsenic metabolism

Inorganic forms (As III and As V species) are bioavailable and toxicologically significant. Inorganic arsenic occurs in groundwater and foods. Food sources include spinach, flour, grape juice, and raw rice.[8] Inorganic forms in water and food are absorbed readily, in contrast to soil arsenic, whose absorption may vary considerably depending on many factors. Soil arsenic may also be available to vegetables[9], and some vegetables are noted to incorporate arsenic within edible parts.[10]

Absorbed inorganic arsenic is distributed throughout the body, excreted into sweat, hair, skin, nails and urine.[11] Absorbed arsenic is cleared from the blood very quickly. The Agency for Toxic Substances and Disease Registry of the US (ATSDR)[12] reports the arsenic urinary half-life is 1-3 days and 24 hours in blood. Hence, any evaluation of blood or urine reflects current exposure.[13].

Inorganic arsenic is metabolized in a two-step process involving reduction of pentavalent arsenic to trivalent arsenic, followed by methlylation to pentavalent organic arsenic by methyl transferase enzymes. This results in the predominant metabolite [dimethylarsinic acid (DMA)], which is rapidly excreted in humans and other mammals. Another metabolite found to a lesser extent in urine is monomethylarsonic acid (MMA). These biomethylation products ("arsenic metabolites") are excreted in the urine and can be measured along with inorganic arsenic.[14] The three constitute the components of

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[7] Environment Canada. Toxic Chemicals in Atlantic Canada- Arsenic. http://www.atl.ec.gc.ca/epb/envfacts/arsenic.html, ISBN #0-662-22948-7
[8] Schoof Ra, Yost LJ, Eickhoff J, Crecelius EA, Cragin DW, Meacher DM, Menzel DB. A market basket survey of inorganic arsenic in food. Food and Chemical Toxicology, 1999;37:839-846
[9] Bunzl K, Trautmannsheimer M, Shramel P, Reifenhouser W. Availability of arsenic, copper, lead, thallium and zinc to various vegetables grown in slag-contaminated soils. J Environ Qual. 2001 May-Jun;30(3):934-9.
[10] Guijarro BF, Carbonell-Barranchina AA< Valero D, Matinez-Sanchez F. Arsenic species: effects on and accumulation by tomato plants. J Agri Food Chem 1999 Mar;47(3):1247-53
[11] Hughes M. Arsenic toxicity and potential mechanisms of action. Toxicology Letters 2002;21113:1-16
[12] The Agency for Toxic Substances and Disease Registry of the US website, 2005. http://www.atsdr.cdc.gov/cgi-bin/search
[13] Hughes, op. cit.
[14] Hughes, op. cit.

arsenic exposure reported by laboratories as “non-dietary arsenic” - preferably called "inorganic arsenic and metabolites". As a group, these are considered the more toxic arsenic entities as compared to arsenic linked to other organic entities such as in arsenosugars or arsenobetaine which are generally found in seafoods. Other metabolites have been noted in chronic arsenical exposure in humans (dimethylarsinous acid and mononothyl arsonous acid). However, by and large, low level exposure can be measured in urine and interpreted accordingly as “non-dietary” arsenic by the measurement of the metabolites DMA and MMA.

1.3.2 Rationale for timing and type of testing

Arsenic toxicity resulting from exposure to dissolved arsenic in drinking water is evident in various geographic areas; the source is generally arsenic from bedrock, not from industrial activity. Researchers have documented significant exposure from drinking water in Taiwan, Argentina, Chile, the Bengal (India) and Bangladesh. Measurable clinical effects have been seen in areas of elevated exposure via drinking water, particularly in Taiwan and Bangladesh, where skin cancer, cardiovascular disease and other outcomes, have a higher prevalence than expected.[15]

Arsenic exposure burden from soil sources is not as well studied. Recent reports from the European Union[16], Germany[17], the United States[18], and Canada (Deloro[19] and Wawa[20]) have provided some insight on the burden of exposure and risk from arsenic in soil. Even though exposure from soil appears to be minimal, the bioavailability of soil arsenic compounds in humans is variable and not well studied.[21]

1.3.2.1 Tests to determine arsenic exposure

There are sensitive and specific laboratory tests to determine the level of arsenic in bodily fluids (blood/serum/urine), hair, nails, and tissues. The application of a particular test to detect levels of inorganic arsenic varies with circumstance.

[15] Anawar HM, Akai J, Mostofa KMG, Safiullan S. Tareq SM. Arsenic poisoning in groundwater heath risk and geochemical sources in Bangladesh. Environment International. 20022;27:597-604

[16] White MA, Sabbioni E. Trace element reference values int issues from inhabitants from the European Union, X. A study of 13 elements in blood and urine of a United Kingdom population.

[17] Seifert B, Becker C, Helm D, Krause C, Shcultz C, Sieiwet M. The GEramn Environmental Survey 1990-1992 (GerES II): Reference concentrations of selected environmental pollutants in blood, urine hair, house dust, drinking water and indoor air. Journal of Exposure Analysis and Environmental Epidemiology 200010(60 part 1:552-565

[18] Komaromy-Hiller G, Ash O, Costa R, Howerton K. Comparison of representative ranges bases on US patient population and literature reference intervals for urinary trace elements. Clinica Chimica Acta 200 ;296:71-90

[19] Cantox Environmental, 1999. Deloro Village Exposure Assessment and Health Risk Characterization for Arsenic and Other Metals, Final Report.

[20] Goss Gilroy Inc. Survey of Urinary Arsenic for Residents of Wawa, Ontario. 2001

[21] Valberg PA, Beck BD, Bowers TS, Keating KL, Bergstrom PD, Beardman PD. Issues in setting health-based cleanup levels for arsenic in soil Regulatory Toxicology and Phamacology 1997;26:219-229

Detection of arsenic in urine

Arsenic in morning urine single specimens correlates well with arsenic in 24-hour urine specimens. Therefore, a single morning urine sample, which is easier to obtain than a 24-hour urine collection, is considered adequate to reflect current exposure. Coupled with analysis for urinary creatinine to provide a signal for urine concentration and to allow for individuals to be at equilibrium with their daily intake, morning urinary arsenic analysis reflects 24-hour urine analysis.[22]

Differences in biomethylation have been observed in children and women[23]. Differences in biomethylation will affect the appearance of organic arsenic metabolites in urine. Some of these are more toxic than inorganic arsenic and can reflect individual susceptibility. However, measurement of biomethylation rates is not an easily applicable tool for community studies, and only urinary arsenic with species analysis for DMMA and MMMA remains the most useful tool to measure arsenic exposure at the community level.[24]

Detection of arsenic in blood

Blood arsenic can change very quickly after a single ingested dose, as the half-life in blood is less than 24 hrs. Blood arsenic may be helpful in cases of very high dose acute oral intoxication, but not in situations where people experience low dose chronic exposures that tend to occur from low level environmental contamination (e.g. of soils).[25] Blood and urine arsenic are measures of recent exposure. However, urine arsenic reflects the dose within the past several days, as the half life is days rather than hours.[26]

Detection of arsenic in hair, nails and tissues

It has been proposed that levels of arsenic in nails and hair determined by standardized testing procedures can be useful to assess long-term exposures to arsenic. The levels detected reflect arsenic deposited at the time of hair and nail growth. The quantitative evaluation of systemic exposure through hair and nail analysis is uncertain.[27] Unfortunately, the analysis of metals in hair does not readily differentiate external contamination from internal (absorbed) arsenic deposited in the shaft of the hair as the hair grows.[28] Nail arsenic reflects arsenic exposure from drinking water very well but

[22] Calderon RL, Hudgens E, Le XC, Schreinemachers D, and DJ Thomas, 1999.Excretion of arsenic in urine as a function of exposure to arsenic in drinking water. Human Studies Division, National Health and Environmental Effects Research Laboratory, Research Triangle Park, North Carolina.

[23] Chung JS, Kalman DA, Moore LE, Kosnett MJ, Arroyo AP, Beeris M, Mazumder DN, Hernandez AL, Smith AH (2002) Family correlations of arsenic methylation patterns in children and parents exposed to high concentrations of arsenic in drinking water. Environ Health Perspect 110(7): 729-33

[24] Hwang YH, Bornschein RL, Grote J, Menrath W, Roda S Urinary arsenic excretion as a biomarker of arsenic exposure in children. Arch Environ Health. 1997 Mar-Apr;52(2):139-47

[25] Ratnaike R N. Acute and chronic arsenic toxicity *Postgraduate Medical Journal* 2003;79:391-396

[26] ATSDR Toxicological profile for arsenic (update). US Department of Health and Human Services 2000

[27] Hinwood A, Sim M, Jolley D, deKerk N, Bastone EB, Gorostamoulos J. Hair and Toenail arsenic concentrations of residents living in areas of high environmental arsenic concentrations. Environmental Health Perspectives 2003 Feb;111(2):187-193.

[28] Hindmarsh JT. Caveats in hair analysis in chronic arsenic poisoning. Clincal Biochemistry 2002;35:1-11

offers little improvement on urinary measures, which are thus preferred.[29] Despite these drawbacks, external tissue arsenic measurement as provided by analysis of hair and nails is useful in forensic examinations of potential arsenic intoxication but, for practical reasons are not used in the context of low level environmental contamination[30]

1.3.2.2 Timing of testing

Generally, we consider toddlers and children as most likely to experience arsenic exposure from unsodded soil during warm months. Seasonal variations in exposure to metals in soil have been clearly shown for lead, for example. Typically soil exposures are higher for children than adults because of frequent direct contact with soils during play and other outdoor activities. During the winter, exposure, and consequently urinary arsenic levels, fall for all groups if soil is purported to be the major exposure pathway. Water remains a constant potential source of exposure year round.

In summary, circumstances and historical experience suggest that testing for arsenic exposure is best done during the early fall and summer months if one desires to capture the potential impact of soil exposure. Timing studies for the fall results in a reflection of upper bounds of potential exposure from soil. As a consequence of this generally accepted approach to community exposure assessment, interpretation of long-term risks should always bear in mind the conditions of testing and the potential attribution to the exposure source. That is to say, for the purpose of evaluating risk from arsenic exposure via soil contamination, data collected in the early fall and summer months will always provide worst-case predictions unless some special conditions of exposure are also demonstrated.

1.3.3 Arsenic exposure in Canada

Food and drinking water are the main sources of arsenic exposure in Canada, respectively. In general, arsenic from soil and air provide less than 0.01 and 0.2 % of total exposure commitment to arsenic in adults. Canadian data indicate that dust and soil provide about 0.4 to 3% of the total daily exposure to arsenic in all age groups with children's exposure commitment being about 4-9% from soil and dust.[31]

Health Canada has estimated that a typical daily intake for an adult in Canada ranges from 1.0×10^{-4} mg/kg/d (0.1 µg per kilogram per day) to 7×10^{-4} mg/kg/d (0.7 µg per kilogram per day). The estimated typical daily intake for a child in Canada (5 to 11 yrs) is from 2.0×10^{-4} mg/kg/d (0.2 µg per kilogram per day) to 2.1×10^{-3} mg/kg/d (2.1 µg

[29] Karagas MR, Le CX, Morris S, Blum J, Lu X, Spate V, Carey M, Stannard V, Klaue B, Tosteson TD. Markers of low level arsenic exposure for evaluating human cancer risks in a US population. Int J Occup Med Environ Health. 2001;14(2):171-5.
[30] Calderon RL, Hudgens E, Le XC, Schreinemachers D, Thomas DJ. Excretion of arsenic in urine as a function of exposure to arsenic in drinking water. Environ Health Perspect. 1999 Aug;107(8):663-7.
[31] Dabeka RW, McKenzie AD, Lacroix GM, Cleroux C, Bowe S, Graham RA, Conacher HB, Verdier P. Survey of arsenic in total diet food composites and estimation of the dietary intake of arsenic by Canadian adults and children. J AOAC Int. 1993 Jan-Feb;76(1):14-25.

per kilogram per day)[32]. These calculations are based on exposure from various pathways including ingestion, inhalation and dermal contact. However, how much arsenic exposure commitment is attributable to each source has not been carefully measured directly in affected groups. The absolute amount of arsenic exposure from soil will vary for each person depending on arsenic concentration in soil, its bioavailability, and the individual's access to the soil (personal habits) and eating of produce grown in the affected soil. Smoking also provides some exposure to arsenic.[33]

1.3.4 Associated health effects

Information on the acute and chronic toxicity of arsenic comes from actual cases of accidental or deliberate ingestion, which does not involve environmental contamination. Long-term effects from environmental exposures from drinking water have been studied in several populations.

1.3.4.1 Acute intoxication

Inorganic arsenic intoxication is accompanied by nausea, vomiting, anemia, abnormal cardiac rhythm and peripheral neuropathy (pins and needles in hands and feet). Short-term (on the order of days to weeks) exposure to high levels of arsenic may result in gastrointestinal irritation, difficulty in swallowing, thirst, abnormally low blood pressure, convulsions, and, in extreme cases, cardiac failure leading to death. The estimated lethal dose for an adult weighing 70 kilograms is in the range of 70 to 280 milligrams. Unborn fetuses, young children, the elderly and chronically ill individuals may be affected at lower levels. Clearly, these clinical events are not observed in conditions of low-level environmental exposures.[34]

1.3.4.2 Chronic intoxication

Symptoms or indications of long-term ingestion of inorganic arsenic may become apparent as skin lesions. These may include darkening or discoloration (hyperpigmentation), skin cornification in palms and soles (skin thickening), and wart-like lesions in palms, soles and torso. Other symptoms include nausea, diarrhoea, decreased production of red blood cells (anemia), abnormal heart rhythm, blood vessel damage, and numbness in the hands and feet. These effects have been observed among populations experiencing high exposure to arsenic from drinking water at concentrations many times greater than those experienced or expected in any Canadian community, even in locally contaminated areas. [35]

[32] Health Canada, 1993. Canadian Environmental Protection Act, Priority Substances List Assessment Report: Arsenic and its Compounds.
[33] Szymanska-Chabowska A, Antonowicz-Juchniewicz J, Andrzejak R. [Plasma concentration of selected neoplastic markers in persons occupationally exposed to arsenic and heavy metals] Med Pr. 2004;55(4):313-20
[34] Ratnaike R N. Acute and chronic arsenic toxicity *Postgraduate Medical Journal* 2003;79:391-396
[35] Health Canada, 2003. Arsenic in Drinking Water. http://www.hc-sc.gc.ca/english/iyh/environment/arsenic.html

Arsenic is classified as a human carcinogen by the International Agency for Research on Cancer[36] (IARC), and the US Environmental Protection Agency[37]. These classifications reflect the human and animal research evidence indicating that arsenic should be treated as a human carcinogen for regulatory purposes. Opinions expressed by experts differ as to how arsenic actually causes cancer. It is known that arsenic can interact with other dietary elements such as selenium (present in foods, especially seafood and fish), and zinc, and that these interactions may modify the effects of arsenic on cells. Antimony may occur as a co-contaminant in drinking water. Its role in arsenic toxicity may be important, but is not well characterized. Although much is written about arsenic's cancer causing effect, there is little known about why rates of some cancers (e.g. skin) are higher in some populations exposed to arsenic, and not as high in others given the same exposure. Cancer risk assessment for arsenic continues to be debated[38].

1.3.4.3 Effects on children and the fetus

Effects on children are likely to be similar to adults. In the presence of maternal toxicity, it is expected that the fetus would be similarly affected, resulting in developmental toxicity. Birth defects have been observed in animals exposed to arsenic but similar observations have not been made in humans. There is insufficient evidence that inorganic arsenic impairs fertility.[39]

[36] IARC website. http://www-cie.iarc.fr/htdocs/monographs/vol23/arsenic.html
[37] US EPA, Website 2004. http://www.epa.gov/ttn/atw/hlthef/arsenic.html
[38] Abernathy C, Liu Y, Longfellow D, Aposhian H, Beck B, Fowler B, et al. 1999. Arsenic: health effects, mechanisms of actions, and research issues, Environ Health Perspect 107:593-597.
[39] ATSDR Toxicological profile for arsenic (update). US Department of Health and Human Services 2000

2.0 Approach and Methodology

This section describes the approach and specific methods used for the study. The study research questions are presented, as well as an overview of study design. Finally, the specific methods used for the different components of the study are presented. The Research Ethics Review Committee (RERC) of the Sudbury District Health Unit (SDHU) reviewed the study methods and processes prior to study implementation.

2.1 Research questions

As previously described, the research team developed the study methodology to address two specific questions that were deemed to be most important by residents:

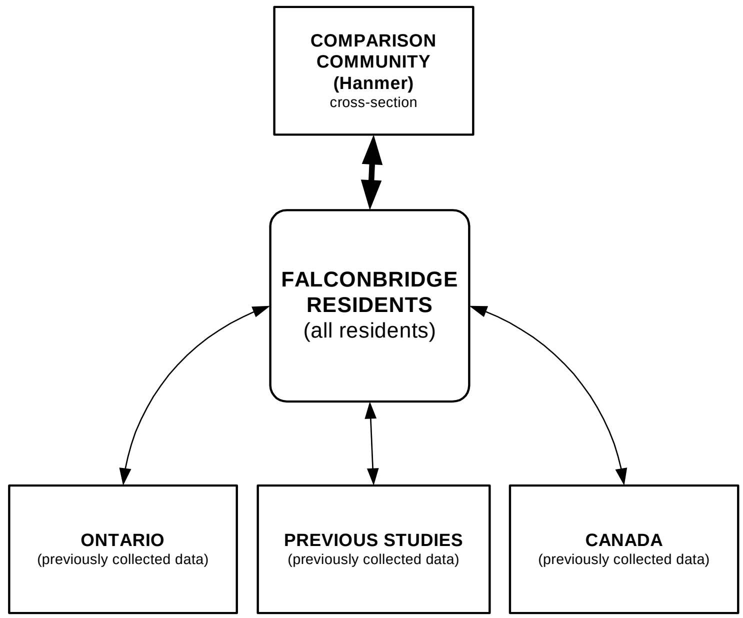
1) *Do Falconbridge residents have higher urinary arsenic levels than residents living in a comparison area with lower levels of arsenic in their soil?* and,

2) *What health risks relative to other communities are associated with the urinary arsenic levels of Falconbridge residents?*

2.2 Study overview

The study was comparative in nature, meaning that the main hypotheses (see questions noted above) imply that a comparison be made between Falconbridge and the comparison community (Hanmer) having lower levels of arsenic in their soil. As well, the study used results from previous studies conducted in Ontario and Canada to make additional comparisons.

Figure 2.1 – Overview of Study Approach



As illustrated in Figure 2.1, all current Falconbridge residents were invited to participate in the study, unless they explicitly expressed on previous occasions that they did not wish to participate. The research team also randomly recruited a similar number of families from the comparison community of Hanmer to participate.

The data collection process was identical in Falconbridge and the comparison community of Hanmer. Initially, potential participants were sent a letter indicating that a member of the study team would be dropping by their house to provide them a sample of the consent form, and to explain the study process. During this time, the team member asked if they were willing to participate in the study, and if yes, scheduled an appointment for the study team to visit them in their home (or alternative site if desired) at their convenience. At the appointment time, the study team walked the participants through the consent/assent forms in detail, had the participants sign them, and then conducted an in-home interview with the adults of the household. At the conclusion of the interview, each family was left a urine sampling kit with instructions, pre-labeled sample bottles, an ice pack, and an insulated bag. The study team then picked up the sample the following morning at a pre-designated time. Sample collection and interviewing occurred between early September and mid-October, 2004.

Samples were processed and shipped to London Health Sciences Trace Elements Laboratory, which analysed all samples for creatinine, total arsenic and inorganic arsenic and its metabolites.

2.3 Selection of comparison community

This section is a brief explanation of the data and methods used to select an area around Greater Sudbury that could be used as a comparison community for Falconbridge. The main objective in selecting a comparison community is to be able to make the statement that "all other things being equal…urinary arsenic levels in Community A with high soil levels are ________ when compared with urinary arsenic levels in Community B with lower soil levels". For the Greater Sudbury Area, a considerable amount of work has been completed in measuring soil levels in various areas. As a result, the study team analysed these soil data to determine potential comparison areas within the region that have lower arsenic levels in their soil (see section 1.2.4). Calculations determined that the community of Hanmer had significantly lower soil levels when compared to Falconbridge.

Sampling within the comparison area was conducted by household via random selection according to a geographic gradient (civic address) within a selected geographic area. One option that can be used to ensure there are relatively even distributions between the two communities (Falconbridge and comparison) for key variables is to conduct stratified random sampling with quotas based on variable categories. For example, based on our knowledge of 20% of Falconbridge residents being under the age of 18, we could sample on the key variable of age with an 20% quota for the variable category of under 18 years old.

One disadvantage to this option is that the collection and sampling in Falconbridge would have needed to be nearly completed before we could have moved in to sampling in the second community. We would have needed to have the participating Falconbridge residents' data set prior to setting quotas for the comparison group. This was of particular concern given that the research team wanted to keep the timing of sample collection or "sampling window" as similar as possible in the two communities.

The other preferred option is to select a slightly larger random sample of households from the geographic comparison area. Then the matching can take place via statistical techniques such as regression. This was the preferred option because we were able to ensure that the samples were collected within the same time period, resulting in a more rigorous study overall.

2.3.1 Random selection of households

Once the comparison community was defined, the survey frame was assembled according to street address (all possible street addresses). The total frame size was divided by the sample size (this establishes the "step" size). A random start point was selected within the step size and then the sample was stepped through. A program using a random numbers table determined the random start point. A similar process was conducted for the replacement sample (i.e. those households that were approached in cases where some households declined to participate).

2.4 Participant recruitment and obtaining consent

Since Fall 2003, information about the study and study planning has been made available to Falconbridge residents via the representatives on the Falconbridge Citizens' Committee, open-houses, community meetings, door-to-door visits and newsletters mailed directly to residents. This process continued up through the time of actual recruitment, and into the period of data collection.

The initial step in recruitment was to mail a brief letter to each household in the Falconbridge area, and the comparison area (Hanmer) that described the overall purpose of the study. Within one week, a member of the research team followed up at their home to discuss the study in more detail, and to drop off sample copies of the consent forms (see Appendix A for consent forms and Appendix B for notification letters). If they were interested in participating, the research team member made an appointment with the family. During the appointment, a research team member went through the consent forms in detail with the members of the household, and had participants sign two copies each. One copy was returned to the researcher. The second copy was left with the member of the household for their own records.

Those participants who were 18 years old or older signed the Adult Consent Form. Those participants between the ages of 7 and 17 years inclusive were given the option of signing the Assent Form. One parent or legal guardian also signed a Child Consent Form for each participant under the age of 18.

2.5 Interview process

Once the research team member received the required signed consent forms and assent forms, the research team member conducted the interview with the adult or adults of the household who were normally most knowledgeable about the family's diet, health issues and daily activities. Interviews were conducted in the participant's home, unless he/she preferred an alternative location. Depending on family size and age of children, the interviews generally lasted between 30 and 60 minutes.

The interview followed a structured protocol (see Appendix C for interview protocol) with specific questions for each household member across the following categories:

- Residential information (current home address, recent time spent elsewhere, age of house, materials used to build house, type of heating used, etc.)
- Indoor activities (amount of time spent indoors, types of activities indoors, type of flooring in most used areas, etc.)

- Outdoor activities (amount of time spent outdoors, types of activities outdoors, exposure to soil, etc.)
- Occupational exposures (current and past occupations, exposure to chemicals at work, showering/changing before coming home, etc.)
- Diet/food (consumption of fish/seafood, specific diets, etc.)
- Play activities (favourite play areas, % exposed soil/dust in play areas, time spent indoors/outdoors, etc.)
- Avoidance behaviours (frequency of specific behaviours in attempts to limit exposure, recent changes in behaviours and activities, etc.)
- Smoking (current smoking status, exposure to second-hand smoke, amount smoked, etc.)
- Medication use (prescribed medications, non-prescribed medications, alternative medications, etc.)
- Health concerns (cancer, skin rashes, kidney problems, etc.)

As part of the quality control process, all completed questionnaires were checked and edited by the Interview Coordinator upon completion by the interviewer. Each participating household received a unique identification number. Each individual participant also received a unique identification number.

2.6 Urine sample collection procedure

As described in a previous section, once residents agreed to participate in the study, signed consent forms, and completed the household interview, they were asked to provide urine samples within a few days of completing the interview. During the interview, the interviewer provided a urine collection kit to the household including the necessary equipment to collect a first morning void sample for each member of the household. The interviewers reviewed the protocol with the household residents to ensure that they understood the process for collecting and cooling the samples (via ice packs). Appendix D contains the Urine Sample Collection Instructions. The research team picked up the samples that same morning.

One urine specimen (preferably early morning void) was required from each individual for analysis. A minimum of 10-20 mL of urine was required. The residents were instructed to collect the sample in a sturdy 125mL NALGENE screw cap bottle (#2104-0004). Participant's name and coding information was attached to the bottle. If not directly collected into the NALGENE bottle, a device for urine collection was used (e.g., for young children, babies, girls and women). These were available from the research team and were pre-tested to ensure they were arsenic-free, and so not able to contribute to contamination of samples.

2.7 Urinary arsenic analysis

The Trace Elements Laboratory of London Laboratory Services Group conducted all analyses of urine. The laboratory provided measures of both "total" and "inorganic" forms of arsenic. The inorganic arsenic measure included As 3+, As 5+, monomethylarsonic acid (MMA) and dimethylarsinic acid (DMA). All samples were also tested for creatinine levels and specific gravity. The analytic process and apparatus are briefly described below. Additional details are contained in Appendix E.

2.7.1 Apparatus

The laboratory used a Finnigan MAT Element High Resolution ICP-MS, which combines the strengths of two established techniques: 1) the ion source (or ICP), a well proven analytical source which operates at temperatures in excess of 8000 K and, 2) a double focusing magnetic sector mass spectrometer used as a detector to separate the elements and their isotopes for subsequent detection and measurement. Resolutions of 380,4800,and 10,500 amu are attainable,compared to only about 300 amu with Low Resolution Instruments.

2.7.2 Overview of materials and methods

Urine samples were analyzed for specific gravity using Bayer Multistix 8 SG and read on a Clintex 500 analyzer (Bayer, Elkhart IN 46515). Creatinine in urine was measured with the Jaffe colorimetric method (1), on a Beckman Synchron LX20 analyzer (Beckman-Coulter, Fullerton CA 92834-3100).

Total urinary arsenic was determined by high-resolution inductively coupled plasma-mass spectrometry (HR-ICP-MS) using a Finnigan MAT Element instrument (Bremen, Germany) directly, after appropriate dilution of the urine. This consisted of inorganic [As^{3+}, As^{5+}, MMA, DMA] and organic species [arsenobetaine + arsenocholine]. The later concentration was determined by the difference between the total amount and the inorganic As. The detection limit is 0.5 µg/L.

Inorganic As was determined by solvent extraction with toluene of the acidified urine after reduction with KI that exclude the organic species (2). Following back extraction of the inorganic As with 1% HNO_3, it was quantitated by HR-ICP-MS. The concentration of inorganic As was determined from a calibration curve of NIST standards similarly treated, and analyzed by HR-ICP-MS. The detection limit is 0.5 µg/L.

Arsenic controls for total and inorganic arsenic and results are presented in Appendix E.

2.8 Notification of individual urinary arsenic results

The *a priori* levels chosen for "normal" ranges were 0-20μg/L for inorganic arsenic and 0-100 μg/L for total arsenic when adjusted for creatinine levels (see Section 4.0). These ranges do not refer to health effects, but rather are population distribution levels where 95% of a population would likely fall within these levels according to previous Canadian studies (e.g., Wawa, Deloro, Sydney).

Any participant who had results outside the *a priori* "normal range" chosen for this study, for either inorganic or total arsenic, was notified by the team physician. As well, if the study team had a consent form allowing release of information to the family physician, the physician was also notified.

For those participants who have an arsenic level in the "normal range", a letter was sent to each individual or his/her parent or guardian outlining the arsenic measure, and a description of what is deemed to be a "normal range" (see Appendix F for samples of individual notification letters).

All notification procedures were under the direction of the team physician, Dr. L. Smith. She was also available to all area physicians for consulting purposes with respect to protocols for re-testing, interpretation, etc.

2.9 Statistical analyses and modeling

2.9.1 Descriptive analyses

In order to gain a picture and understanding of the Falconbridge residents' data and that of the comparison area, the research team created a profile of the communities (see Section 3.0). The profiles describe current exposure levels for arsenic measured in the study according to basic demographics. The profiles were based on reporting simple measures of central tendency (e.g., mean, median) and variability (e.g., standard deviation) with continuous variables, and proportional distributions for categorical variables. These profiles used data sources such as the questionnaire and interview data, and lab analyses of samples.

2.9.2 Comparative analyses

The research team conducted statistical analyses for questions posed regarding how Falconbridge residents compare to the Hanmer residents. Depending upon the nature of measurement for specific variables, statistical tests designed to determine the presence of significant differences were performed using univariate tests where appropriate. As well, prior to any analysis, the data were assessed to ensure that they met the specific test assumptions (e.g., heterogeneity of variance, normality). When warranted, alternatives were implemented (e.g., data transformation procedures, non-parametric tests).

2.9.3 Analysis of associated variables

Regression models were developed to assist in identifying variables that could account for some portion of the variance in urinary arsenic levels. The primary technique used for these analyses was multiple linear regression models. These are described in Appendix G.

3.0 Community profiles

3.1 Response rates

Falconbridge. 273 households were invited to participate in the study of which 148 (54%) agreed. In addition, there were 20 households (7%) willing to participate but not available during the data collection period due to reasons such as vacation, illness, or work schedules. Ninety-three households (34%) refused to participate in the study. Reasons for refusal varied but included "not interested in study", "don't perceive there is a problem", "believes that they are too old", or "not enough time available". The study team was unable to contact any adult residents of the remaining 12 households (5%). Overall, information was collected for 393 participants in the interview portion of the study and, of these, 369 participants provided a urine sample.

Hanmer. Out of the 360 households approached, 129 (36%) agreed to participate in the study. Interviews captured information on 335 respondents and 321 participants provided urine samples.

Table 3.1 summarizes the distribution of participating households and individual participants in both Falconbridge and Hanmer for both the interview and sample portions of the study.

Table 3.1 - Summary of study participants

Community	# of Participating Households	# of Participants (# of Samples)	# of Urine Samples			
			Adults (18 and over)	Children 0-5	Children 6 – 12	Children 13 - 17
Falconbridge	148	393 (369)	268 (73%)	18 (5%)	53 (14%)	29 (8%)
Hanmer	129	335 (321)	226 (70%)	17 (5%)	61 (19%)	17 (5%)
Total	277	728 (690)	494 (72%)	35 (5%)	114 (16%)	46 (7%)

Participants of the two communities provided a total of 690 urine samples, the results of which are provided below along with a summary of the corresponding questionnaire data.

3.2 Sociodemographic profiles of participants[40]

One first step with respect to understanding community level exposures to arsenic using a comparison community approach is to determine the similarity of the two

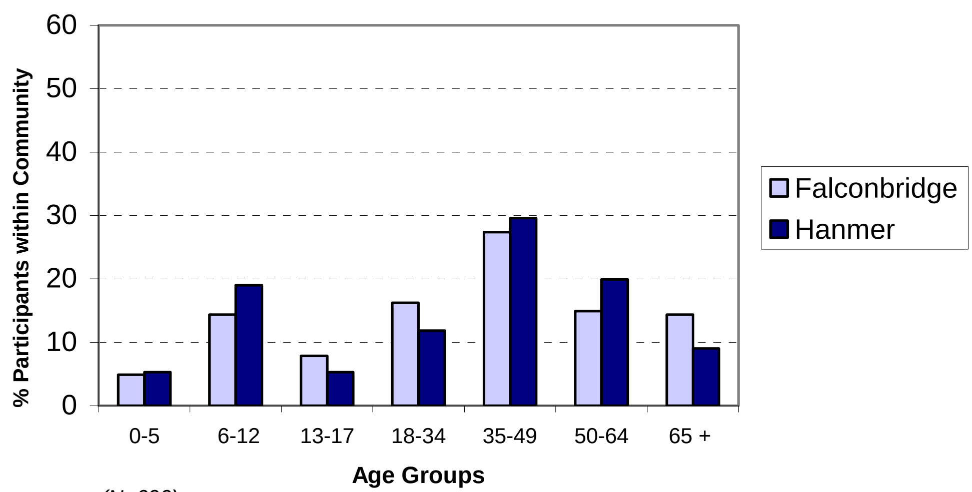
[40] For clarity in interpreting tables, any missing responses to questions have been removed from the analysis. The number of respondents (N) for each question has been provided.

community samples on variables that could potentially be associated with exposure to arsenic (e.g., outdoor activities, age, sex, diet). This section presents the profile of the two samples of participants from each community on some key variables.

3.2.1 Age

As illustrated below in Figure 3.1, the age distribution of the two samples followed a similar pattern with a slightly higher proportion of 6-12 year olds and 50-64 years olds in Hanmer, and slightly higher proportions of 18-34 year olds and 65 years or older in Falconbridge. The average ages for the communities were similar (Falconbridge with mean=37.9 years; SD=22.5 vs. Hanmer with mean=36.1 years; SD=21.2), and were not statistically significantly different (t=1.06; df=688; p>0.05).

Figure 3.1 - Age distribution by community



(N=690)

3.2.2 Sex

As illustrated in Table 3.2, the distribution of the two samples according to sex was very similar with approximately equal proportions of males and females participating from each community.

Table 3.2 - Sex of participants

	Falconbridge N=369	Hanmer N=321	Total N=690
Male	189 (51.2%)	156 (48.6%)	345 (50.0%)
Female	180 (48.8%)	165 (51.4%)	345 (50.0%)

3.2.3 Education

The highest levels of education attained for participants by community are presented in Table 3.2. The distribution of secondary and post-secondary education levels is similar across the two communities, with approximately one-half of participants having some form of post-secondary education (e.g., college, university).

Table 3.3 – Highest education level (18 years and older)

	Falconbridge N=262	Hanmer N=220	Total N=482
Less than High School	16 (6.1%)	23 (10.5%)	39 (8.1%)
High School	95 (36.3%)	78 (35.5%)	173 (35.9%)
Post Secondary	143 (54.6%)	108 (49.1%)	251 (52.1%)
Other	8 (3.1%)	11 (5.0%)	19 (3.9%)

3.2.4 Residence

As illustrated in Table 3.4 below, the length of time that adults had spent in their current community was similar for both Falconbridge (M=21.9 years; SD=17.8) and Hanmer (M=21.8 years; SD=16.6). This gives an indication that the communities are similar to the extent that they have similar proportions of relatively new residents and longer-term residents.

Table 3.4 - Length of time in community (years)

	Falconbridge N=266	Hanmer N=221	Total N=487
Mean	21.90	21.8	21.9
Standard Deviation	17.84	16.56	17.26
Median	17.00	18.00	17.00
Minimum	0.17	0.08	0.08
Maximum	76.00	81.00	81.00

When adult participants reported how many years they had spent in their current residence, the average lengths of time were similar in both communities as illustrated in Table 3.5 below.

Table 3.5 - Length of time in current residence (years)

	Falconbridge N=267	Hanmer N=223	Total N=490
Mean	15.5	14.4	15.0
Standard Deviation	12.79	12.28	12.56
Median	13.00	11.00	12.00
Minimum	0.17	0.08	0.08
Maximum	68.00	53.00	68.00

3.3 Health and lifestyle profiles of participants

3.3.1 Tobacco use among adult participants

Current tobacco use among adult participants in the two communities is presented in Table. 3.6. The proportion of current tobacco users among the Falconbridge participants was higher (32%) in comparison to the Hanmer participants (25%).

Table 3.6 - Tobacco use (18 and older)

	Falconbridge N=264	Hanmer N=219	Total N=483
Uses tobacco	85 (32.2%)	54 (24.7%)	139 (28.8%)
Smokes Cigarettes	82 (31.1%)	50 (22.8%)	132 (27.3%)
Other Tobacco	7 (2.7%)	2 (0.9%)	9 (1.9%)
Does Not Use Tobacco	179 (67.8%)	165 (75.3%)	344 (71.2%)

3.3.2 Exposure to second-hand smoke

Participants who did not use tobacco themselves indicated in the interview to what extent they were exposed to second-hand smoke in their homes, car or at other locations (e.g., work, babysitter's house). Slightly fewer non-smokers in Hanmer reported being exposed to smoke in the house (18% vs. 22% in Falconbridge), however, a slightly larger proportion reported being exposed in the car (14% vs. 9% in Falconbridge).

Table 3.7 - Exposure to second hand smoke

	Falconbridge	Hanmer	Total
In the house	61 (21.6%) N=282	49 (18.4%) N=266	110 (20.1%) N=548
In the car	24 (8.7%) N=277	35 (13.7%) N=256	59 (11.1%) N=533
Other locations	52 (19.3%) N=269	51 (19.2%) N=265	103 (19.3%) N=534

3.3.3 Self-reported health problems

Table 3.8 contains the health problems that participants reported in each of the communities. It should be noted that these proportions have not taken into account age or gender distributions, two common characteristics that are often directly associated with health issues. As previously illustrated in Figure 3.1, although the average ages of the two samples were very similar, the distribution of age differed slightly with higher proportion of participants aged 65 years and older in the Falconbridge sample (14%) when compared with the Hanmer sample (9%).

The proportion of reported health problems were relatively similar across the two samples. Approximately 40% of participants in each community reported that they had no health problems. Similar proportions reported "other health problems" which consisted primarily of high blood pressure and asthma in each sample. In the case of liver disease, skin cancer and lung cancer, the number of observations was suppressed due to few responses in each category.

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Table 3.8 - Reported health problems

	Falconbridge N=369	Hanmer N=321	Total N=690
High cholesterol	70 (19.0%)	60 (18.7%)	130 (18.8%)
Diabetes	21 (5.7%)	20 (6.2%)	41 (5.9%)
Liver disease	**	**	**
Gastrointestinal problems	38 (10.3%)	43 (13.4%)	81 (11.7%)
Skin cancer	**	**	14 (2.0%)
Lung cancer	**	**	**
Bladder cancer	0	0	0
Skin rashes or lesions	63 (17.1%)	53 (16.5%)	116 (16.8%)
Other cancer	19 (5.1%)	10 (3.1%)	29 (4.1%)
Other	133 (36.0%)	127 (39.9%)	260 (37.7%)
None	151 (40.9%)	126 (39.3%)	277 (40.1%)

* * number of observations suppressed due to small counts (N <10); multiple responses possible

3.3.4 Consumption of fruits and vegetables from garden

Approximately 42% of Hanmer residents reported eating fruits and/or vegetables from their home garden. In contrast, approximately one-quarter (27%) of Falconbridge residents indicated that they consumed fruits and/or vegetables from their gardens.

3.4 Hand and face washing patterns

One of the main routes for soil ingestion is via hand to mouth contact for children. Participants were asked whether children (12 years of younger) generally washed their hands before eating, ate with utensils, and washed their hands and face before going to bed. As illustrated in Tables 3.9 – 3.11, the proportions of self-reported behaviours were similar across the communities.

Table 3.9 - Hands washed before eating (12 years and under)

	Falconbridge N=71	Hanmer N=77	Total N=148
Usually (75-100%)	43 (60.6%)	53 (68.8%)	96 (64.9%)
Sometimes (25%-75%)	18 (25.4%)	16 (20.8%)	34 (23.0%)
Rarely (0-25%)	10 (14.1%)	8 (10.4%)	18 (12.2%)

Table 3.10 - Eat with utensils (12 years and under)

	Falconbridge N=66	Hanmer N=77	Total N=143
Usually (75-100%)	60 (90.9%)	73 (94.8%)	133 (93.0%)
Sometimes (25%-75%)	2 (3.0%)	3 (3.9%)	5 (3.5%)
Rarely (0-25%)	4 (6.1%)	1 (1.3%)	5 (3.5%)

Table 3.11 - Hands washed before going to sleep (12 years and under)

	Falconbridge N=70	Hanmer N=75	Total N=145
Usually (75-100%)	63 (90.0%)	56 (74.7%)	119 (82.1%)
Sometimes (25%-75%)	4 (5.7%)	9 (12.0%)	13 (9.0%)
Rarely (0-25%)	3 (4.3%)	10 (13.3%)	13 (9.0%)

4.0 Urinary arsenic levels

This section describes the urinary arsenic levels for Falconbridge and the comparison community of Hanmer. Initially, the levels of inorganic arsenic and its metabolites (referred to in the remaining sections as "inorganic arsenic") are presented, followed by the results from the analyses of total arsenic[41,42]. This is followed by the details from statistical tests that were conducted to determine whether differences between communities were significant from a statistical perspective. Finally, the research team examined the results obtained from Falconbridge and Hanmer and compared them to those obtained in previous studies in various locations in Canada and other countries. These results are then compared with the levels that Health Canada have published with respect to typical daily intake of arsenic for children and adults in Canada overall, and those who live near point sources of arsenic.

In December 2004, the research team physician notified participants of their individual results for inorganic and total urinary arsenic. Those individuals who had samples that tested at or above the *a priori* determined level of 20μg/L for inorganic arsenic and 100μg/L for total arsenic when adjusted for creatinine levels were visited in their homes by the team physician to discuss their results and receive referrals for follow-up 24-hour testing under the supervision of their family physicians. All other participants who had levels within the ranges below the *a priori* determined referral levels were provided their results by mail with contact information for the team physician if they had any questions.

4.1 Inorganic arsenic levels

4.1.1 Distribution of levels by community

The distributions of urinary inorganic arsenic levels are presented in Figure 4.1 according to the two communities. The distributions are relatively similar with positive skewing (predominance of lower levels) occurring in the distribution for each community. Approximately 80% of the urine samples in each community had an

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[41] The units of measurement used in this report are μg of arsenic per litre of urine (μg/L). This is the unit that is most commonly used in much of the scientific literature, so has been used in this report for comparison purposes.

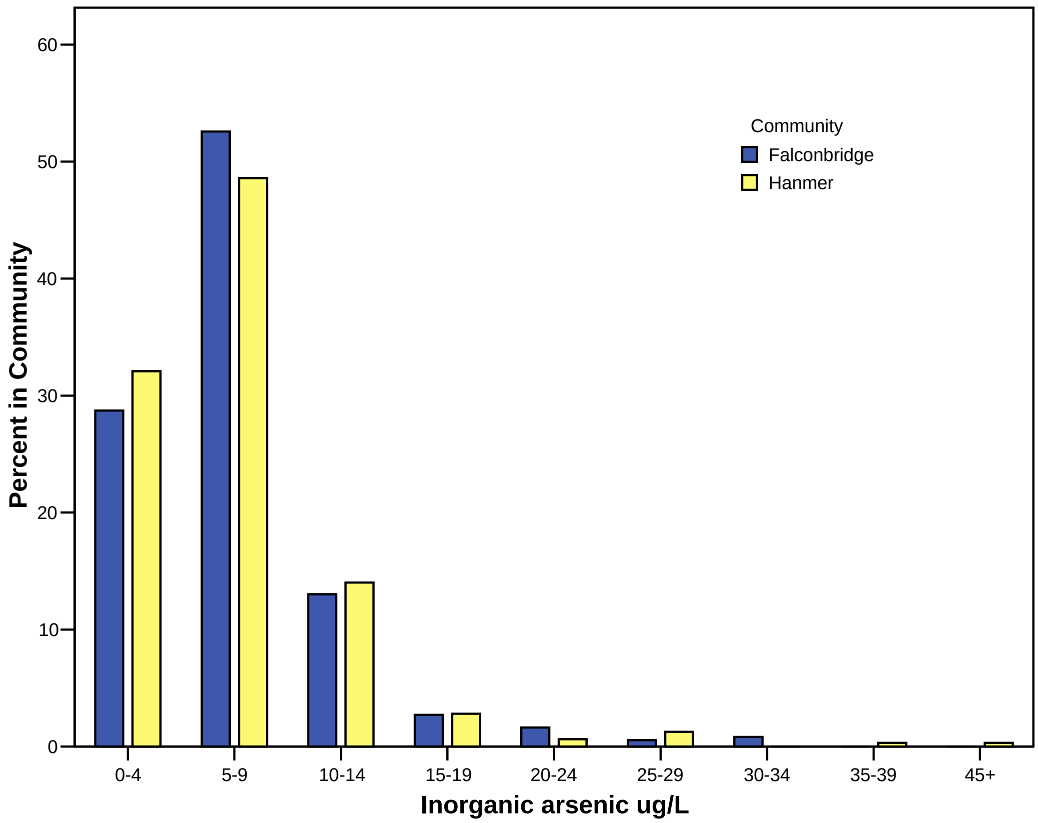
[42] The values presented in this report have not been adjusted for creatinine levels. This has recently been suggested as an appropriate approach when analyzing community levels in population studies (see Hinwood, et al, 2002). For the purposes of reporting individual levels, which are more appropriately reported making an adjustment for creatinine levels, the team converted the units of μmol/mol to a comparable μg/L unit using the equation:

$$As\left(\frac{ug}{L}\right) = \frac{As\left(\frac{umol\ \text{As}}{mol\ \text{Creatinine}}\right)\left(\frac{mmol\ \text{Creatinine}}{L\ \text{Urine}}\right)(\text{Molecular Weight As})}{1000}$$

Parallel analyses were run with non-adjusted and adjusted values. As Hinwood 's (2002) research would suggest, there were no differences in the conclusions from the statistical tests if adjusted or non-adjusted values were used.

inorganic arsenic level measured at below 10µg/L. Approximately 2-3% of samples in each community were at or above 20µg/L.

Figure 4.1 – Distribution of urinary inorganic arsenic levels



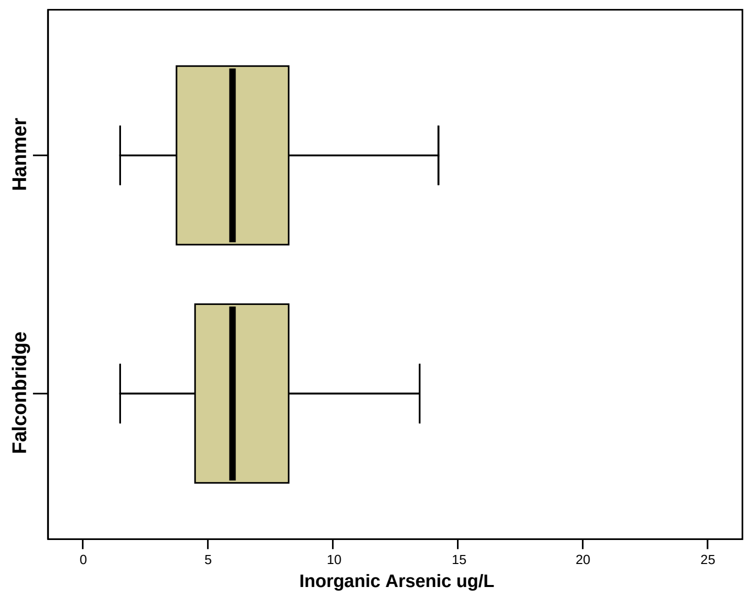
As illustrated in Table 4.1 below, the average measures of inorganic arsenic in urine samples were similar across communities. The arithmetic mean for Falconbridge samples was 7.11µg/L in comparison with 7.19µg/L in Hanmer. Similarly, the medians (the point at which 50% of measures fall above and 50% fall below) for each of the communities were similar: 5.99µg/L in both communities. Finally, the geometric mean (also known as the logarithmic mean) was also similar for each community: 6.10µg/L in Falconbridge and 6.02µg/L in Hanmer.

Table 4.1 - Inorganic arsenic measures (μg/L)

	Falconbridge N=369	Hanmer N=321	Total N=690
Arithmetic Mean	7.11	7.19	7.14
Standard Deviation	4.53	5.63	5.07
Median	5.99	5.99	5.99
Minimum	1.50	1.50	1.50
Maximum	32.96	67.41	67.41
Geometric Mean	6.10	6.02	6.06

The box plots[43] shown in Figure 4.2 are presented to illustrate information similar to that in Figure 4.1. They more clearly show the overlap of the distributions for urinary inorganic arsenic measures in the samples in the two communities.

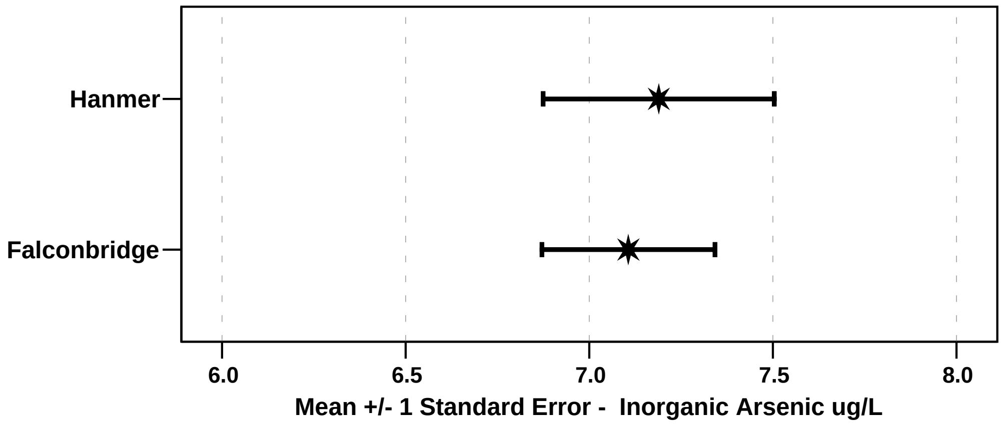
Figure 4.2 – Box plots of inorganic arsenic levels by community



Similarly, the mean and standard error of the mean presented graphically below in Figure 4.3 illustrate the overlap of the distributions of urinary inorganic arsenic levels in the two communities.

[43] The box plots have been developed so that the bold vertical bar in the middle of the box represents the median. The edges of the box represent the inter-quartile range (between the median of the lowest group and the median of the highest group). The horizontal lines represent the distance of one-half quartile beyond the box (or 11/2 quartiles beyond the median). Outliers have not been indicated on this plot.

Figure 4.3 – Mean and standard error for inorganic arsenic by community



4.1.2 Distribution of levels by age

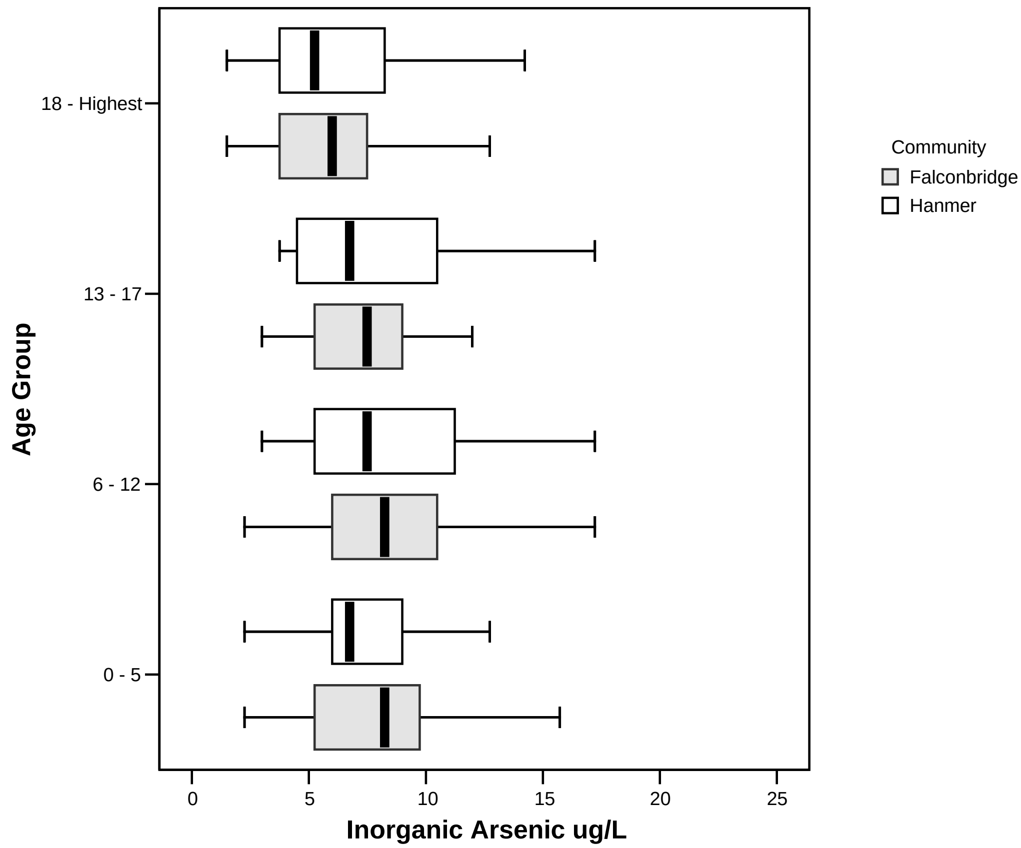
The urinary inorganic arsenic levels were also analysed by age. As illustrated in Table 4.2, levels generally decreased with increasing age, with children ages 6-12 years with the highest average values compared to the other age groups.

Table 4.2 - Inorganic arsenic (μg/L) by age

	0-5 years		6-12 years		13-17 years		18+ years	
	Falconbridge N=18	Hanmer N=17	Falconbridge N=53	Hanmer N=61	Falconbridge N=29	Hanmer N=17	Falconbridge N=269	Hanmer N=269
Mean	8.66	7.53	9.51	9.30	7.77	7.89	6.46	6.54
SD	4.65	3.69	6.45	6.24	4.32	4.18	3.87	5.56
Median	8.23	6.74	8.24	7.49	7.49	6.74	5.99	5.24
Minimum	2.25	2.25	2.25	3.00	3.00	3.75	1.50	1.50
Maximum	20.22	15.73	32.96	38.20	26.96	17.23	32.21	67.41
Geo. Mean	7.50	6.64	8.04	7.94	7.03	6.99	5.62	5.48

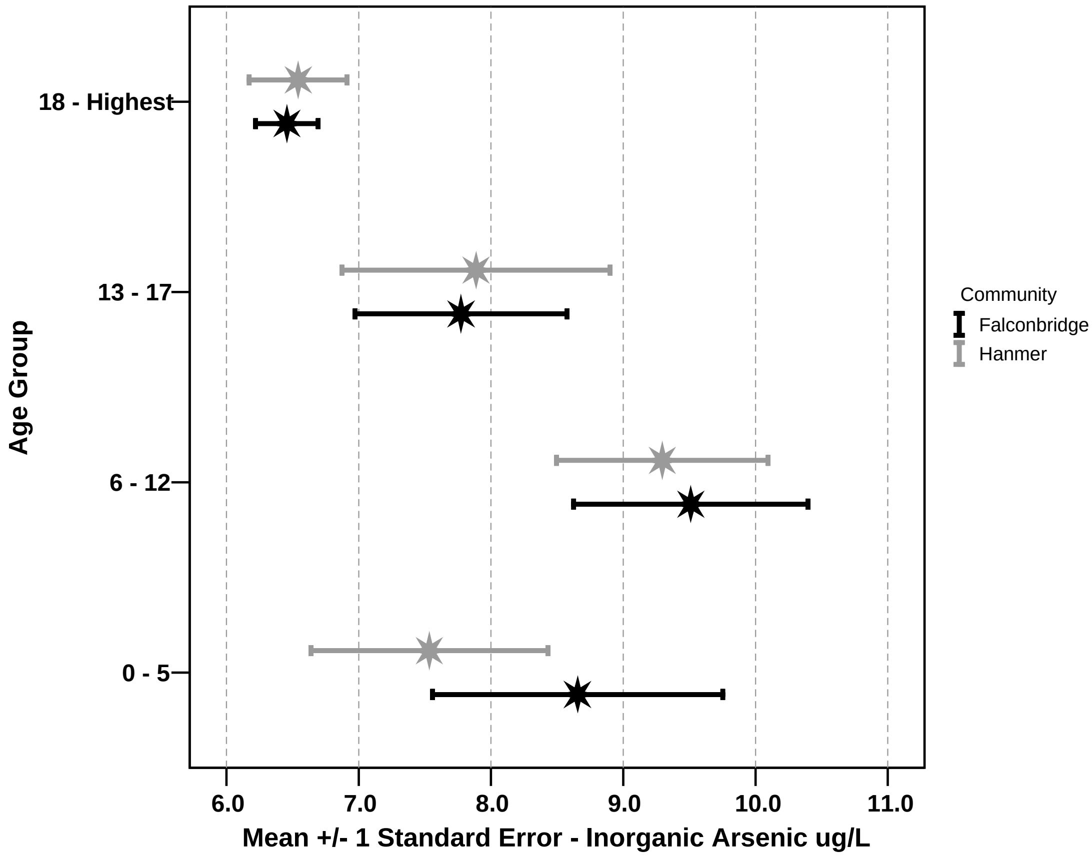
The box plots by age group and community are presented in Figure 4.4. The overlap of boxes represents an overlap in distributions of measured levels.

Figure 4.4 - Box plots of inorganic arsenic levels by age



Similarly, the means and standard error for inorganic arsenic presented in Figure 4.5 below depict the overlaps between distributions across the two communities.

Figure 4.5 – Mean and standard error for inorganic arsenic by age group



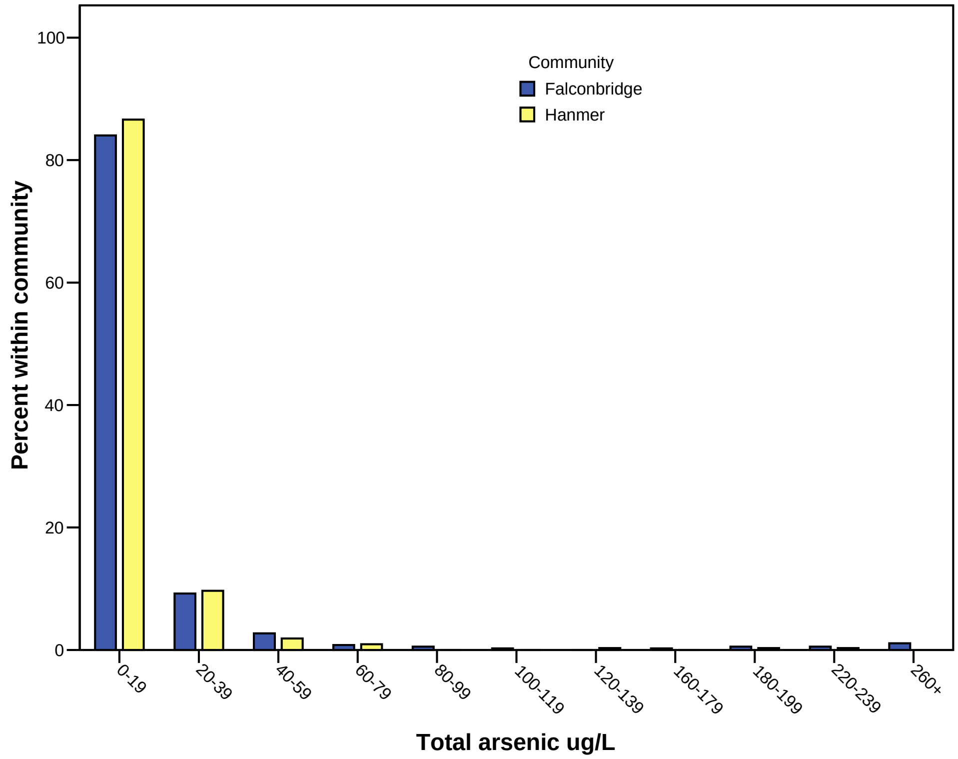
4.2 Total arsenic levels

As previously mentioned, total arsenic results measure the levels of inorganic arsenic described above in addition to the organic forms. The levels of measured urinary total arsenic are presented according to community and age group.

4.2.1 Distribution of levels by community

As illustrated in Figure 4.6, the overall distributions of total arsenic levels are similar for the two communities. In Falconbridge, there were two extreme outliers of approximately 600μg/L and 900μg/L. The distribution is positively skewed with over 80% of the samples measured with levels below 20μg/L. Approximately 2-3% of samples in each community were at or above 100μg/L.

Figure 4.6 – Distribution of urinary total arsenic levels



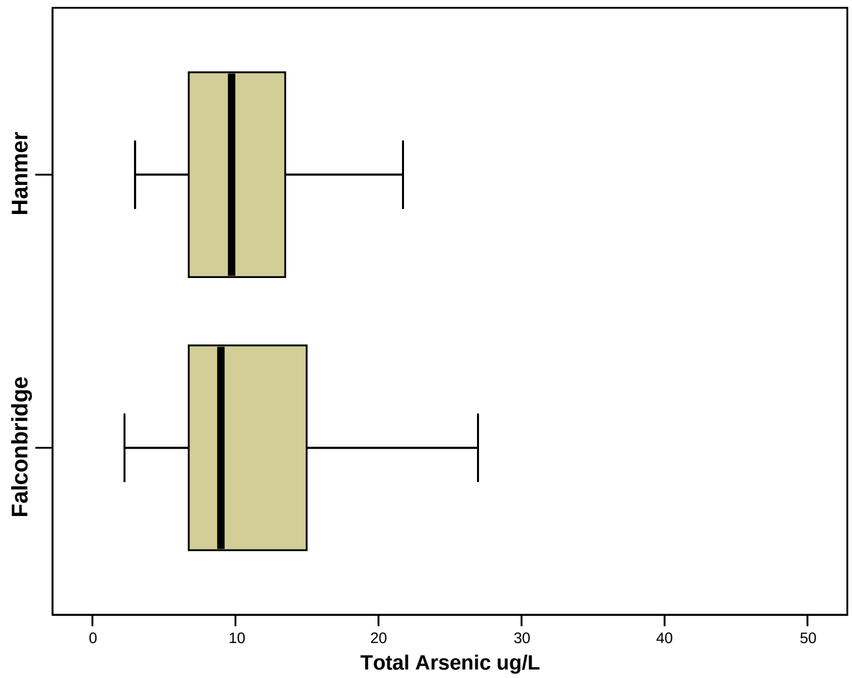
As illustrated in Table 4.3 below, some of the central tendency measures of total arsenic in urine samples are similar across communities. The median for each of the communities was similar: 8.99µg/L in Falconbridge and 9.74µg/L in Hanmer. As well, the geometric mean (also known as the logarithmic mean) was also similar for each community: 10.69µg/L in Falconbridge and 10.33µg/L in Hanmer. When the arithmetic mean was examined, it was found that the mean for Falconbridge was 21.24µg/L in comparison with 14.10µg/L in Hanmer. At least part of this difference can be attributed to the two very extreme outliers that have more influence on the arithmetic mean as a measure of central tendency in comparison to their impact on measures such as the median or the geometric mean.

Table 4.3 - Total arsenic measures (µg/L)

	Falconbridge N=369	Hanmer N=321	Total N=690
Mean	21.24	14.10	17.92
Standard Deviation	64.52	19.83	49.18
Median	8.99	9.74	9.36
Min	2.25	3.00	2.25
Max	903.29	235.94	903.29
Geometric Mean	10.69	10.33	10.52

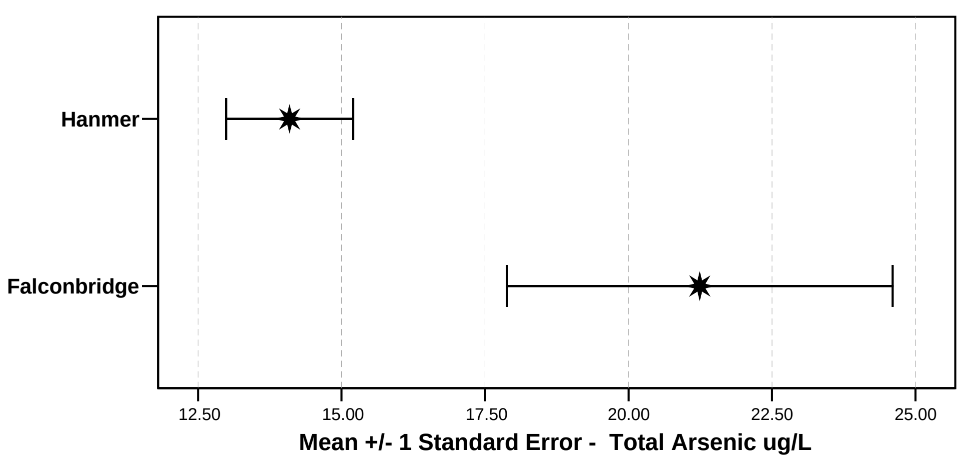
The box plots shown in Figure 4.7 are presented to illustrate information similar to that in Figure 4.6. They more clearly show the overlap of the distributions for urinary total arsenic measures in the samples in the two communities.

Figure 4.7 – Box plots of total arsenic levels by community



The means and standard errors presented in Figure 4.8 below illustrate the influence that the two extreme scores found in Falconbridge have on the mean compared to the medians presented in Figure 4.7 above.

Figure 4.8 - Mean and standard error for total arsenic by community



4.2.2 Distribution of levels by age

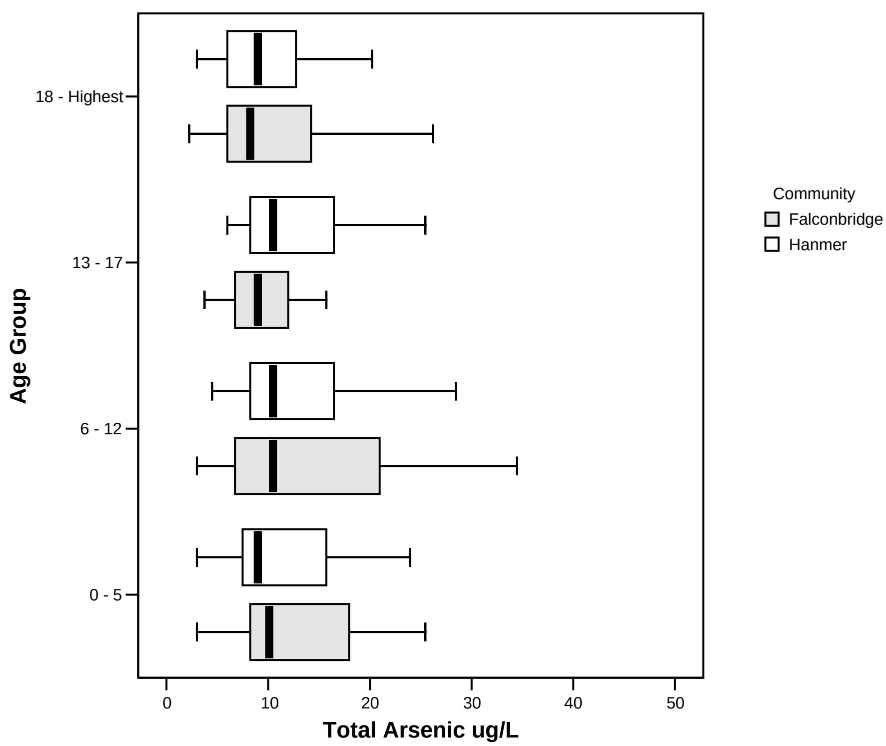
The urinary total arsenic levels were also analysed by age and are presented in Table 4.4. Similar to the inorganic levels, the total levels generally decreased with age, with children ages 6-12 years with the highest average values compared to the other age groups.

Table 4.4 - Total arsenic (μg/L) by age

	0-5 years		6-12 years		13-17 years		18+ years	
	Falconbridge N=18	Hanmer N=17	Falconbridge N=53	Hanmer N=61	Falconbridge N=29	Hanmer N=17	Falconbridge N=269	Hanmer N=269
Mean	31.25	18.90	37.83	15.04	13.53	13.35	18.13	13.54
SD	73.25	30.88	126.07	12.35	16.76	6.78	46.76	21.09
Median	10.11	8.99	10.49	10.49	8.99	10.49	8.24	8.99
Minimum	3.00	3.00	3.00	4.49	3.75	5.99	2.25	3.00
Maximum	321.32	136.32	903.29	73.40	92.88	29.96	575.23	235.94
Geo. Mean	13.22	11.68	13.49	12.33	10.09	12.01	10.12	9.65

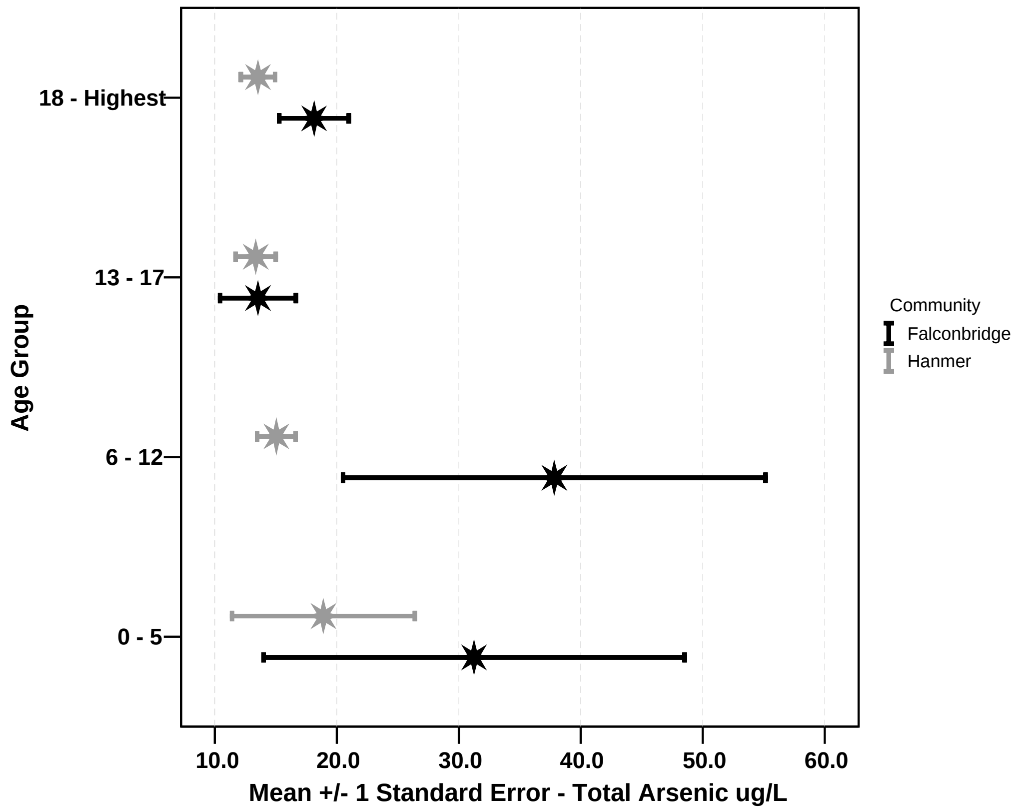
The box plots by age group and community are presented in Figure 4.9. The overlap of boxes represents an overlap in distributions of measured levels.

Figure 4.9 - Box plots of total arsenic levels by age



Similar to Figure 4.8, the impacts of extreme outliers on the mean and standard errors are evident in Figure 4.10, particularly in the 6-12 year old age group.

Figure 4.10 - Mean and standard error for total arsenic by age group



4.3 Statistical comparisons for communities

The differences between communities' levels were assessed using both parametric (independent t-test) and non-parametric (Mann-Whitney U) statistical tests. For independent t-tests, an initial test of homogeneity of variance was completed (Levene's test). In cases of heterogeneity of variance, an adjusted independent t-test formula was used. The overall purpose of all tests was to determine if there were statistically significant differences between communities for either urinary inorganic arsenic levels or urinary total arsenic levels.

4.3.1 Inorganic arsenic comparisons

As illustrated in Table 4.5, the research team found no statistically significant differences for inorganic arsenic levels overall or by age groups when comparing Falconbridge and Hanmer.

Table 4.5 – Comparison of communities for inorganic arsenic

	Independent t-test			Non-parametric	
	t-value	df	p-value	Mann-Whitney U	p-value
All participants	0.21	688	0.83	58,019	0.64
Infants, Toddlers, Pre-schoolers *(0-5 years)*	0.79	33	0.44	131	0.46
Children *(5-12 years)*	0.18	112	0.86	1,578	0.83
All children *(0-12 years)*	0.40	147	0.69	2,643	0.63
Teens *(13-17 years)*	0.09	44	0.93	236	0.80
Adults *(18+ years)*	0.20	493	0.84	29,378	0.52

4.3.2 Total arsenic comparisons

As illustrated in Table 4.6 below, when total arsenic levels were compared using an independent t-test, Falconbridge was found to have significantly higher levels than Hanmer. However, when the non-parametric test was conducted (Mann Whitney U), there was no significant difference. This is likely due to the two extreme outliers found in Falconbridge which will have impacted on the mean (used for t-tests calculations), while the ranking and medians used in the Mann Whitney would be more robust to extreme outliers. As illustrated in Table 4.6, the age group analyses did not produce any statistically significant differences between communities.

Table 4.6 – Comparison of communities for total arsenic

	Independent t-test			Non-parametric	
	t-value	Df	p-value	Mann-Whitney U	p-value
All participants	2.02	446	0.04*	57,929	0.62
Infants, Toddlers, Pre-schoolers *(0-5 years)*	0.64	33	0.53	137	0.59
Children *(5-12 years)*	1.31	53	0.20	1556	0.73
All children *(0-12 years)*	1.48	73	0.14	2,735	0.90
Teens *(13-17 years)*	0.04	44	0.97	179	0.12
Adults *(18+ years)*	1.45	387	0.15	29,972	0.79

** significant – p<0.05*

4.4 Comparisons with other studies

When compared with results from other studies, the Falconbridge and Hanmer levels of inorganic arsenic were similar to other recent studies. The reader should be aware that not all of the studies cited below have necessarily used the same analytic procedures, or collection procedures, and, as a result, some proportion of difference is likely due to the differences in approaches. It is impossible to determine to what extent the small differences that are observed are as a result of true differences in arsenic levels, differences in collection and analyses, or characteristics of participants (e.g., sex, age, etc.).

Table 4.7 – Recent arsenic studies

Study/ Place	Objectives	Type of study	Special techniques	Comparisons	Variables	Results for Inorganic As
Canadian Studies						
Falconbridge, Ontario 2004	**exposure survey** Children and adults	Population based Cross sectional Fall sampling (late summer) to optimize external exposure Comparison community of Hanmer **Overall N=690** Falconbridge N=369 Hanmer N=321 **Under 13 N=149** Falconbridge N=71 Hanmer N=78	Single morning urine Face to face interviews with household Analysis ICP-MS Detection limit 0.0005 µmol/L	Comparison community with low As soil levels Compared to literature	Age, sex, recent fish intake, smoking in household, soil contact, etc. Inorganic and Total As	**Overall Mean =7.2 (5.6)** Falconbridge Mean = 7.1(4.5) Hanmer Mean= 7.2 (5.6) Falconbridge range= 1.7-32.6 Hanmer range= 1.7-67.1 **Under 13 Mean = 9.1 (5.6)** Falconbridge Mean= 9.3 (6.0) Hanmer Mean= 8.9 (5.8) Falconbridge range= 2.5-32.6 Hanmer range = 2.0-38.1
Wawa, Ontario 2001	**exposure survey** Children and adults	Population based Cross sectional Fall sampling(late summer) to optimize external exposure overall N=184 Under 13 N= 44	Single morning urine Face to face interviews with household Analysis ICP-MS Detection limit 0.0005 µmol/L	Stratification by As soil concentrations within community Ontario community used in Deloro, 1999 study Compared to literature	Age, sex, recent fish intake, smoking in household, soil contact, etc. Inorganic and Total As	**Overall Mean =5.6 (4.4)** Overall range= 0.3-25.2 **Under 13 Mean = 7.0 (5.1)** Overall range= 0.3-20.5
Wawa, Ontario 2002	**exposure survey** Children only, larger sample than previous year.	Population based Cross sectional Fall sampling(late summer) to optimize external exposure Under 13 N= 53	Two morning urine As samples taken one week apart Face to face interviews with household Analysis ICP-MS Detection limit 0.0005 µmol/L	Stratification by As soil concentrations within community Compared to literature Compared to literature and to previous study in Wawa	Age, sex, recent fish intake, smoking in household, soil contact, etc. Inorganic As	**Under 13 Mean = 5.6 (3.4)** Overall range= 0.6-15.5

Study/ Place	Objectives	Type of study	Special techniques	Comparisons	Variables	Results for Inorganic As
Deloro, Ontario Mine tailings 1999	**exposure survey** Adults and children	Deloro Village N =121 Havelock , ON as a comparison N = 53	Single morning urine Face to face interviews with household Analysis Graphite furnace AAS – reporting limit of 6µg/L	Comparison community of Havelock Compared to literature	Age, sex, recent fish intake, smoking in household, soil contact, etc. Inorganic and Total As	**Overall** **Deloro Mean =4.36 (4.0)** Deloro range= 3.0-22.9 **Havelock Mean =4.57 (4.0)** Havelock range= 3.0-20.0 **Under 13** **Deloro Mean =5.34 (5.6)** Deloro range= 3.0-22.9 **Havelock Mean =7.01 (4.4)** Havelock range= 3.0-12.72
Sydney, Cape Breton, Nova Scotia 2002 "Sydney Tar Ponds" former coke oven site	**exposure survey** Adults and children	Volunteers from several affected and non-affected areas near former coke oven site. June sampling (early summer) Overall N=372 Under 13 N=236	Single morning urine Analysis ICP-MS Detection limit 0.0005 µmol/L	Coke ovens site (Whitney Pier, North End, and parts of Ashby) and outside site (NOCO) Compared to literature	Age, sex, recent fish intake, smoking in household, soil contact, etc. Inorganic As	**Overall Mean =6.4 (8.2)** Overall range= 0.8-71.2 **Under 13 Mean = 6.7(9.5)** Overall range= 0.8-71.2

Study/ Place	Objectives	Type of study	Special techniques	Comparisons	Variables	Results for Inorganic As
Non-Canadian Studies						
Hwang 1997 **USA** Anaconda, Montana 1992-3 Closed down copper smelter Soil As 121 - 236	**exposure survey** **Child-specific arsenic sources to determine relative impact on exposure** **To determine constant and low level exposure**	Population based cross sectional Summer collection to optimize external exposure N=414 **children** under 72 mo *Double urine collection on consecutive days to establish stable estimate* and *Third composite sample by 12 noon* and *24 children selected for 24 hr urine As*	Door to door census Personal interviews Soil samples top 2 cm Analysis Graphite furnace AAS	No control community Compared to literature Sub group had double sampling on consecutive days	House dust individual yard soil SES Residence location House condition and General environmental conditions Ht, wt, surface area Creatinine, specific gravity (surface area) Measures Interior surface dust Drinking Water-tap Urine samples Soil composite: play area, garden, sand box; parking area gravel	**Under 6 Mean** 8.6 ug/l Conclusions: 1. Average levels of urinary As are low. 2. Dose response with environmental concentrations (within these low values)
Hysong et al. 2003 **USA** Winkelman, AZ (farther from smelter) Hayden, AZ (close to smelter) June - October 1999 Closed down copper smelter	**Exposure survey** Speciated As >10 only (N=106)	Cross sectional population based N=404 questionnaires only N=224 urine samples and house dust (few under 29 provide urine)	Door to door census Personal interviews (self administered) House dust samples	Two communities with different soil As levels and proximity to smelter	House dust Occupation SES Age of home Water source Diet (seafood, garden produce, etc.) Home heating Personal risk factors (smoking)	**Overall** Mean = 12.3 Hayden Mean = 12.6 Winkelman Mean = 11.7

Study/ Place	Objectives	Type of study	Special techniques	Comparisons	Variables	Results for Inorganic As
Hinwood et al. 2004 **Australia** Residential As in soil 9 – 9900 ppm Control residential As in soil 1.7 - 80 ppm	**Exposure survey** Control population with similar demographic profile as study pop'n. No industries.	Cross sectional survey N= 107 residents Exposed = 55 Control= 52	Door to door visits, participants recruited in person 3 drinking water samples in three separate periods 3 urine samples over a week, and 2 other samples over the year composite soil samples house dust samples			Exposed mean uAs 1.64 ug/l Control mean uAs 1.18 ug/l (significant)

4.5 Comparison with Health Canada models

Another set of comparisons that the research team developed was with the estimated typical daily intake models for inorganic arsenic that have been developed by Health Canada[44]. In order to make comparisons, the research team used a model that was developed for and reported in the Wawa 2001 report. The purpose of the model was to estimate the approximate inorganic levels found in urine based on inorganic arsenic intake. The model estimated that urinary arsenic levels for inorganic arsenic and its metabolites would be approximately 1.7µg/L to 1.9µg/L for an intake of approximately 0.1µg/kg-day. It should be noted that these urinary arsenic levels are based on notional factors for bioavailability and the relationship between urinary and blood concentrations of arsenic. There will be differences in the relationship from individual to individual due to physical difference as well as short term variations related to the intake of naturally occurring arsenic. For additional details on the derivation of these values, please refer to Appendix H.

Illustrated in Table 4.8 below, the median levels measured in Falconbridge are all within the lower portions of the estimated ranges of intake for the average daily intake for Canadians. For the child groups, the maximum observed levels are also within this typical range. For the teen group, the maximum observed level was slightly above the range but well below the upper bound of the estimates for Canadian living near point sources. For adults, the maximum observed level was higher than the estimated range for average daily intake, but well below the upper bound of the range for Canadians living near point sources.

Table 4.8 - Comparisons of observed Falconbridge medians and maximum level of inorganic arsenic with Health Canada's Average Daily Intake for Canadians and for Canadians living near point source for arsenic

	Canadian		Canadian Living Near Point Source		Falconbridge	
	Estimate Range (µg/kg/d)	*Estimate Range* (µg /L urine)*	*Estimate Range (µg /kg/d)*	*Estimate Range* (µg /L urine)*	*Median (µg /L urine)*	*Maximum (µg /L urine)*
Infant & Toddler	0.1-2.6	1.8-46.8	0.1-14.0	1.8-252	8.2	20.2
Child	0.2-2.1	3.6-37.8	0.2-23.0	3.6-414	8.2	33.0
Teen	0.1-1.3	1.8-23.4	0.1-11.0	1.8-198	7.5	30.0
Adult	0.1-0.7	1.8-12.6	0.1-12.0	1.8-216	6.0	32.2

* Converted to urinary arsenic levels by assuming 0.10µg/kg/day = 1.8 µ g/L urine

[44] *Arsenic and its Compounds: Canadian Environmental Protection Act – Priority Substances List Assessment Report (1993)* Health Canada

5.0 Factors associated with arsenic levels

The research team developed various statistical models (regression) to examine to what extent various factors were associated with urinary arsenic levels. The overall models included one model for all participants, and then separate models for each community. The rationale for developing separate models for each community was to determine if there were different patterns of associations between a factor and urinary arsenic in each community. These models were examined separately for both inorganic and total arsenic levels.

In addition to the overall models, a child behaviour model was developed based on questions that focused on child participants under 13 years of age. This model was also used to examine patterns of association for all child participants, and patterns for each community. They were used to assess the associations with inorganic arsenic, and total arsenic with specific factors.

Multiple linear regression analysis was the statistical technique used to predict either inorganic arsenic levels or total arsenic levels. The regression equation used was simply:

$$\hat{Y} = b_0 + b_1 X_1 + b_2 X_2 + \ldots b_p X_p$$

where b_0 represents the intercept, and b_1 , b_2,…. b_p are the regression coefficients for the predictors X_1, X_2,….X_p.

5.1 Overall models for inorganic arsenic

The summary[45] of the overall models is presented in Figure 5.1. The factors included in the model to determine predictive associations with inorganic arsenic levels were:

- Age
- Sex
- Community (for overall model only)
- Exposed to tobacco smoke either 1st or 2nd hand
- Smoking status
- Reported having above average exposure to soil and/or dust in previous seven days due to certain activities
- Ate food cooked over campfire in previous seven days

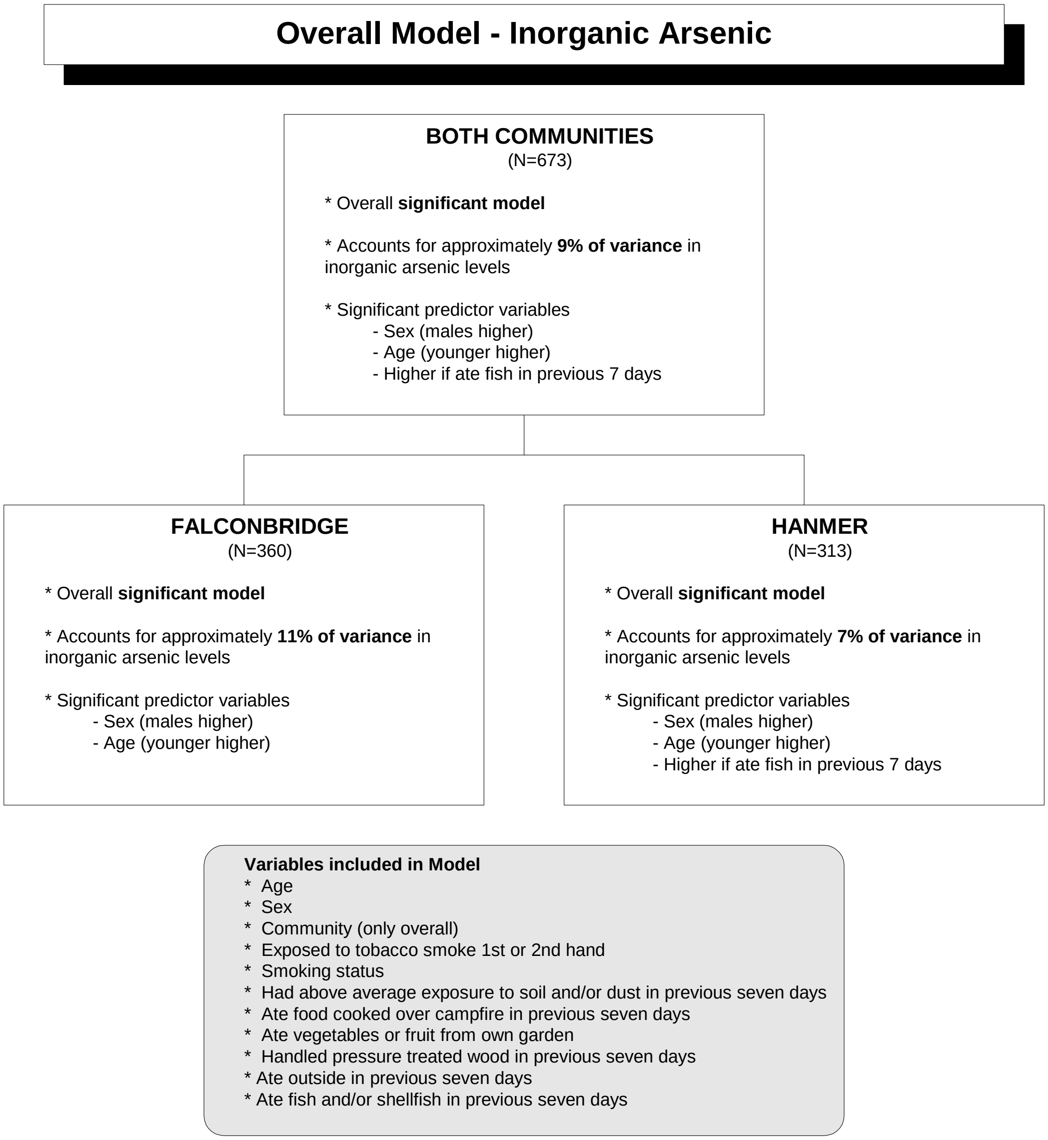
[45] The summaries of the linear regression models are presented in this section. For the detailed statistics of the regression models, please refer to Appendix G.

- Ate vegetables or fruit from own garden in previous seven days
- Handled pressure treated wood in previous seven days
- Ate outside in previous seven days
- Ate fish and/or shellfish in previous seven days

The overall models were significant for all participants, and for each community. For the overall model with all participants included, the main variables that were found to be associated with urinary inorganic arsenic levels were age (younger people have higher levels), sex (males tend to have higher levels), fish consumption within the past seven days (consumption associated with higher levels).

The overall model for Falconbridge demonstrated that the significantly associated variables included age and sex. Hanmer had the same pattern as that found in the overall model.

Figure 5.1 - Overall model for inorganic arsenic



5.2 Child models for inorganic arsenic

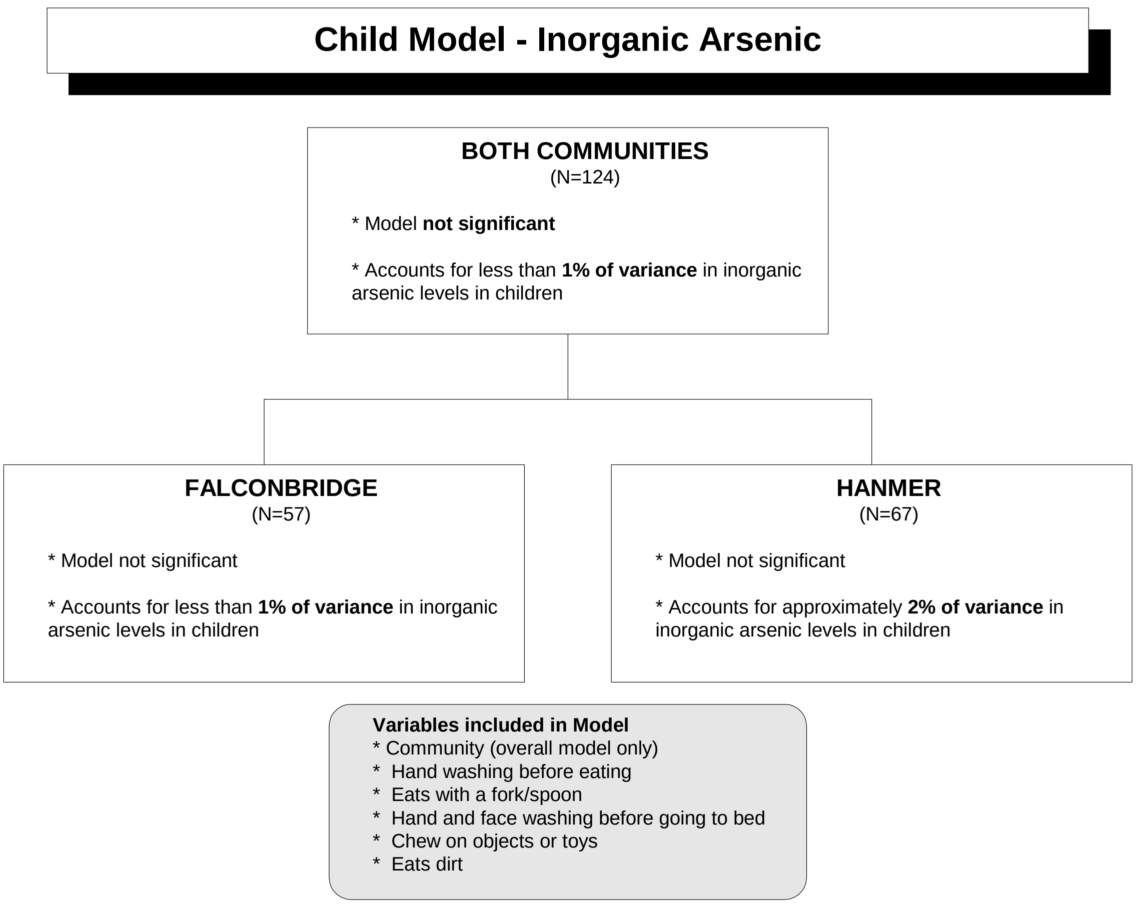
The summary of the child models is presented in Figure 5.2. None of these models was significant.

The factors included in the model to determine predictive associations with inorganic arsenic levels were:

- Community (for overall model only)
- Hand washing before eating

- Eating with a fork/spoon
- Hand and face washing before going to bed
- Chewing on objects or toys
- Eating dirt

Figure 5.2 – Child models for inorganic arsenic



5.3 Overall models for total arsenic

The summary of the overall models for total arsenic is presented in Figure 5.3. All of the overall models were significant. The same predictor factors were used for the total arsenic models that were used for the inorganic models, namely:

- Age
- Sex
- Community (for overall model only)
- Exposed to tobacco smoke either 1st or 2nd hand
- Smoking status

- Reported having above average exposure to soil and/or dust in previous seven days due to certain activities
- Ate food cooked over campfire in previous seven days
- Ate vegetables or fruit from own garden in previous seven days
- Handled pressure treated wood in previous seven days
- Ate outside in previous seven days
- Ate fish and/or shellfish in previous seven days

The overall model for all participants produced significant associations between total arsenic levels and age (younger people have higher levels), sex (males have higher levels), fish consumption in past 7 days (consumers have higher levels), community (Falconbridge has higher levels), and eating food cooked over a campfire in the past 7 days (consumers have higher levels).

The patterns differed when the research team examined the models according to community. For Falconbridge, the only significant association was between eating food cooked over a campfire in the past 7 days (consumers have higher levels). In contrast, for Hanmer, there were three significant associations with urinary total arsenic levels: sex (males have higher levels); fish consumption (ate fish in last 7 days – higher levels); and eating food cooked on campfire (higher if ate food in past 7 days).

Figure 5.3 - Overall model for total arsenic

Overall Model - Total Arsenic

BOTH COMMUNITIES
(N=673)

* Overall **significant model**

* Accounts for approximately **6% of variance** in inorganic arsenic levels

* Significant predictor variables
  - Sex (males higher)
  - Age (younger higher)
  - Community (Falconbridge higher)
  - Higher if ate food cooked over campfiire in previous seven days
  - Higher if ate fish in previous 7 days

FALCONBRIDGE
(N=360)

* Overall **significant model**

* Accounts for approximately **8% of variance** in inorganic arsenic levels

* Significant predictor variables
  - Higher if ate food cooked over campfire in previous seven days

HANMER
(N=313)

* Overall **significant model**

* Accounts for approximately **7% of variance** in inorganic arsenic levels

* Significant predictor variables
  - Sex (males higher)
  - Higher if ate food cooked over campfire in previous seven days
  - Higher if ate fish in previous 7 days

Variables included in Model
* Age
* Sex
* Community (only overall)
* Exposed to tobacco smoke 1st or 2nd hand
* Smoking status
* Had above average exposure to soil and/or dust in previous seven days
* Ate food cooked over campfire in previous seven days
* Ate vegetables or fruit from own garden
* Handled pressure treated wood in previous seven days
* Ate outside in previous seven days
* Ate fish and/or shellfish in previous seven days

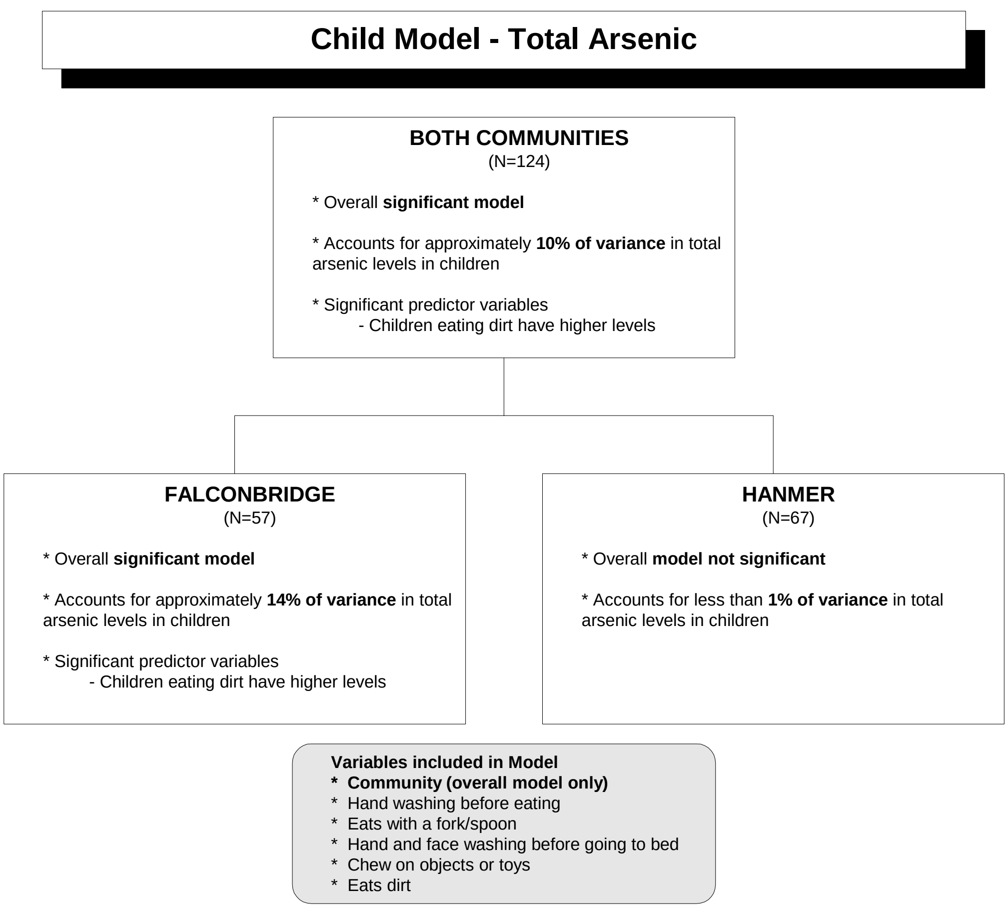
5.4 Child models for total arsenic

The summary of the child models is presented in Figure 5.4. Similar to the models developed for predicting inorganic arsenic levels, the models for total arsenic included the following factors:

- Community (for overall model only)
- Hand washing before eating
- Eating with a fork/spoon
- Hand and face washing before going to bed
- Chewing on objects or toys
- Eating dirt

The model was significant for all child participants and the Falconbridge child participants. The significant association among both models was with the children who were reported to eat dirt had higher levels of total arsenic.

Figure 5.4 – Child models for total arsenic



6.0 Discussion

This section provides a discussion of the results obtained in the current study. The initial portion of this discussion focuses on addressing the two original research questions posed. The second portion of the discussion focuses on some of the limitations and challenges associated with the study.

6.1 Study research questions

The study was designed to answer two main research questions. In this section the research team provides answers to each question based on the results from the study.

> *Do Falconbridge residents have higher urinary arsenic levels than residents living in a comparison area with lower levels of arsenic in their soil?*

<u>No</u>. Falconbridge residents' urinary arsenic levels were very similar to those in the comparison community of Hanmer. With respect to ***inorganic arsenic***, the type of arsenic most closely associated with health effects, the average levels in each community were nearly identical. Falconbridge residents had a mean level of 7.1µg/L and a median level of 6.0µg/L in comparison with Hanmer residents who had a mean level of 7.2µg/L and a median level of 6.0µg/L. An examination of the distribution of the levels in each community indicated that approximately 80% of the urine samples in each community had an inorganic arsenic level measured at below 10µg/L, and approximately 2-3% of samples in each community were at or above 20µg/L. Statistical comparisons between the communities did not reveal any statistical differences overall or by various age groups.

With respect to ***total arsenic*** (both organic and inorganic forms), the communities again demonstrated similar distributions of urinary arsenic levels. The median level among Falconbridge residents was 8.9µg/L compared to 9.7µg/L for Hanmer residents. The mean levels were 21.2µg/L for Falconbridge residents compared to 14.1µg/L for Hanmer residents. There were two extreme outliers measured in the Falconbridge community that had a strong impact on the mean, but limited impact on the median as a measure of central tendency. The distribution is positively skewed with over 80% of the samples measured with levels below 20µg/L. Approximately 2-3% of samples in each community were at or above 100µg/L. Statistical comparisons (non-parametric – Mann Whitney U) that were less influenced by extreme outliers indicated that there was not a statistically significant difference between the two communities. The statistical comparisons that tested the difference between means (independent t-test) found that

Falconbridge residents had statistically higher average levels of total arsenic when compared to Hanmer residents.

For the forms of arsenic that are most generally accepted to be most toxic to humans (inorganic arsenic), the two communities have nearly identical average levels. When we examine total arsenic levels that include both inorganic arsenic levels and organic arsenic levels (generally obtained through diet), we found that Falconbridge residents have similar levels with the exception of two extreme outliers.

What health risks relative to other communities are associated with the urinary arsenic levels of Falconbridge residents?

Falconbridge and Hanmer residents on average are within the typical daily intake of arsenic by Canadians, and therefore are not at any increased risk from arsenic exposure as compared to other Canadians in general.

Health risks associated with urinary arsenic levels for Falconbridge residents would be similar to those in the comparison community of Hanmer. The median levels in Falconbridge are within the lower portion of the range estimated for typical daily intake of arsenic by Canadians (Health Canada).

Dirt and other factors which could be related to soil arsenic intake (washing hands, eating dirt, etc) constitute a larger variance of total arsenic in urine in Falconbridge children up to age 13 as compared to Hanmer children. This is not the case however, for inorganic arsenic in urine in both communities, where the variances are similar and the model is not significant.

What these results indicate is that Hanmer and Falconbridge children are under similar influences for total arsenic in urine, even though Falconbridge children have a slightly different attribution of the total arsenic levels associated with soil intake potential activities. However, this is not the case for inorganic arsenic, which is the arsenic we would expect to have that relationship if soil were the most important contributor to arsenic exposure.

With respect to absolute risk, however, it is known that arsenic exposure in general in Canada is close to or above the toxicological boundaries of increased cancer risk. Health Canada uses the rates of 1/1,000,000 or 1 in 1/100,000 as an acceptable risk. However, most arsenic exposures in Canada provide a toxicological risk level above this level. What this means is that according to the mathematical risks of cancer, much of our ordinary arsenic intake as Canadians will be calculated as an increased risk.

For arsenic, the question is then, are Falconbridge or Hanmer residents experiencing an additional preventable risk because of their geographic location, the soil levels, or other circumstances? This study indicates that, on a community level, neither Falconbridge nor Hanmer shows preventable sources of environmental arsenic exposure, and in particular, not a soil-related risk of elevated inorganic urinary arsenic.

6.2 Challenges and limitations

As with any study, this one presented challenges and has limitations. These are briefly discussed below.

Survey design. We chose a cross-sectional, once-only survey design to capture a snap-shot representation of exposure to arsenic in two communities. The generalizability of the results arises from assumptions about the nature of exposure to contaminants found primarily in soil. All things being equal, with a large enough sample, we assume that the average levels in the community during this period would reflect exposure fluctuations throughout the year on an individual basis and that the averages found represent average exposures for individuals.

Seasonal timing of the survey. Data collection for the current survey was completed during September and early October, 2004. Literature on surveys which depend on soil contaminant exposure opportunity supports the choice of late summer or early fall as a representative period during which to measure children's exposure. Summer patterns have been established and therefore, actual representative exposure is more likely to result. In addition, earlier summer collection presents difficulties with resident summer absences and travel. The choice of this period also corresponds to previous surveys in other communities.

Models used to determine relationship between arsenic intake and urinary arsenic levels. The current study used estimates for the conversion of intake amounts to corresponding urinary arsenic levels. These were developed for a previous study (Wawa, 2001). It should be noted that these urinary arsenic levels are based on notional factors for bioavailability and the relationship between urinary and blood concentrations of arsenic. This modeling carries with it some level of uncertainty as there are always physical differences between individuals that can affect the assumptions used in the modeling (e.g., blood volumes, kidney function, lean body mass and urinary creatinine). There will be differences in the relationship from individual to individual due to physical difference as well as short term variations related to the intake of naturally occurring arsenic.

Response rate. The ideal response rate is 100%; however, this is an ideal that is rarely achieved, particularly in community based studies. The response rates achieved for this study were 54% in Falconbridge and 36% in Hanmer. In order to determine if there was potential systematic bias in the samples, the research team attempted to compare the samples achieved with an overall profile of the population to determine to what extent the group differed in age and sex[46]. The samples were very similar to the population data available. While it is impossible to rule out all potential sources of bias, it is unknown to what extent remaining differences between the sample and the population could impact on urinary arsenic levels.

[46] See Appendix I for the details of this comparison.