

**Arsenic in Groundwater from
Domestic Wells in Three
Areas of Northern Alberta**

R E P O R T

Arsenic in Groundwater from Domestic Wells in Three Areas of Northern Alberta

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In response to public concern about arsenic levels in groundwater in the Cold Lake region, the *Arsenic in Groundwater in Cold Lake Area Working Group* conducted a project to monitor Arsenic in groundwater in three areas of Northern Alberta between January of 1999 and June of 2000. Alex Mackenzie led the monitoring project. Robert Audette, Weiping Chen, and Donald Schopflocher conducted data analysis, data interpretation, and prepared the final report. The Working Group played an important role in study design, sampling strategies, technical advice, communication strategies, and risk management. Environmental health inspectors from Lakeland Regional Health Authority (RHA), Aspen RHA and Keeweenok RHA carried out field collection. The Trace Elements/Environmental Toxicology Laboratory performed the trace metal analyses. Dr. Steve Hrudey provided an independent review focusing on human health risk assessment. The assistance of Dr. Nicholas Bayliss (Medical Officer of Health, Lakeland RHA), Dr. Paul Schnee (Medical Officer of Health, Aspen RHA) and Dr. Ken Hodgins (Medical Officer of Health, Keeweenok RHA) in sample collection, of Dennis Prince (Water West Consulting) in sampling design, of Erik Ellehoj (Ellehoj-Redmond Consulting) in mapping, and of all participants and local communities is gratefully acknowledged.

EXECUTIVE SUMMARY

Objective

This report provides information on the occurrence of arsenic in groundwater from domestic wells in the Lakeland Regional Health Authority (RHA), Aspen RHA, and Keeweenok RHA in Northern Alberta. The report examines arsenic concentrations in relation to various underlying bedrock geological formations, seasons of the year, other trace metals, and with water treatment. A human health risk assessment based on available information is then presented.

Methodology and Analysis

A total of 2,817 of water samples from domestic wells were collected over a 13-month period (February 1999 to March 2000). Arsenic along with twenty two other trace metal elements were analyzed, using a PE-SCIEX^R Elan 6000 Inductively Coupled Plasma – Mass Spectrometer (ICP-MS) operating in the quantitative mode with internal standardization. Statistical analysis was performed on summary measures of arsenic concentrations in relation to geographic areas and underlying bedrock geological formation variations, seasonal variation, treatment method variation, and relationships to twenty-two other trace metal elements. Scientific literature and regulatory documents related to drinking water guidelines for arsenic were reviewed. A qualitative statement for human health risk related to drinking arsenic-containing water was provided.

Findings

The principal findings of this study include the following two aspects:

Characteristics of Arsenic in Groundwater

- Annual average arsenic concentrations in excess of 25 µg/L (*Canadian Drinking Water Guideline for Arsenic*) were observed in 21.9% of the raw water samples in Lakeland RHA, 3.9% in Aspen RHA, and 19.5% in Keeweenok RHA;
- The arsenic levels exceeded 50 µg/L in 12.2% of the raw water samples in the

Keeweenaw RHA;

- No systematic seasonal variation of mean arsenic concentration values was observed;
- Elevated arsenic concentrations in domestic well waters were associated with areas underlain by three bedrock geological formations - the LaBiche Formation, the Lea Park Formation and the Smoky Group in Northern Alberta- all of which are marine formations containing shale.
- Elevated arsenic concentrations were most likely to be observed in domestic well waters in wells greater than 50 feet in depth;
- Relatively strong relationships were observed among concentrations of arsenic, iron, and molybdenum;
- The sample sites from the areas underlain by the Smoky Group, the Lea Park Formation, and the LaBiche Formation appear to have different profiles of trace elements;
- The small numbers and unequal distributions of types of water treatment do not allow strong statistical conclusions to be drawn about their differential effectiveness.

Exposure and Potential Health Risk

- The average intake of arsenic from drinking water for the majority of residents in three RHAs falls within a typical Canadian intake;
- Annual average exposure to levels of arsenic from drinking local domestic well waters is considerably lower than the levels reported to cause adverse health effects in the scientific literature;
- Although there is general consensus about the health risks posed by high concentrations of arsenic in drinking water, there is no direct evidence on which to base risk estimation for levels of arsenic at or below the current drinking water guidelines or standards.

Recommendations

The responsibility for the safety of private well-drinking water lies with the property owner. For the purpose of protecting the health of the resident individuals, as well as the health of others, the following recommendations can be made:

- Well owners should actively monitor arsenic concentrations in their well water.
- One-time elevated arsenic levels, exceeding the recommended 25 µg/L Drinking Water Guideline require repeated sampling and monitoring.
- If arsenic levels in a domestic well water consistently exceed 25 µg/L, an alternate source of potable water should be used for consumption and food preparation, or ways to reduce arsenic levels in the well water should be implemented.
- People with individual health concerns should visit their family physicians for advice.

TABLE OF CONTENTS

Executive Summary.....	i
Introduction	1
Arsenic in Groundwater Survey.....	3
Materials and Methods	3
Sampling Locations	3
Field Collection	7
Trace Element Analysis	8
Statistical Analysis.....	9
Results	10
Sampling Information	10
Arsenic Concentrations by Regional Health Authority.....	11
Seasonal Variation.....	11
Geographical and Geological Variation.....	12
Associated Trace Elements	17
Water Treatment	21
Exposure and Potential Health Risk.....	23
Arsenic Sources and Concentrations in Groundwater.....	23
Treatment Technology.....	25
Exposure.....	26
Health Effects.....	27
Arsenic Risk Assessment	29
Conclusions.....	35
Recommendations	36
References	38

LIST OF FIGURES

Figure 1 Locations of the Three Regional Health Authorities	3
Figure 2 Sampled Well Sites by Underlying Bedrock Geological Formations	5
Figure 3 Mean Arsenic Levels and Monthly Variation by Well Site	12
Figure 4 Sample Sites by Latitude, Longitude and Formation	13
Figure 5 Distribution of Mean Arsenic Levels by Underlying Bedrock Formation	14
Figure 6 Distribution by Well Depth within Geological Formation	15
Figure 7 Distribution of Mean Arsenic Levels by Category of Underlying Formation and Depth of Well	16
Figure 8 Biplot of Relationships among Trace Elements and Underlying Bedrock Geological Formations	18
Figure 9 Arsenic Levels for Treated and Untreated Water.....	21

LIST OF TABLES

Table 1 Description of Geological Formations	6
Table 2 Samples and Sample Types	10
Table 3 Percentage of Average Arsenic Concentrations in Raw and Treated Water.....	11
Table 4 Annual Average Concentrations ($\mu\text{g/L}$) of Trace Elements.....	20
Table 5 Estimate of Excess Lifetime Skin Cancer Risk Associated with Arsenic.....	30
Table 6 Premature Risk from Various Causes	31
Table 7 Adverse Health Effects after Continuous Exposure	32

INTRODUCTION

In the summer of 1994, relatively high levels of arsenic were found in some domestic well waters in the Cold Lake region of Northeastern Alberta. Under a Canada-Alberta Environmentally Sustainable Agriculture Agreement (CAESA), an Alberta Farmstead Water Quality Survey was conducted across Alberta between 1994-1996 by a partnership consisting of Alberta Health and Wellness, the Regional Health Authorities (RHAs), the University of Alberta Hospital (UAH) - Trace Elements/ Environmental Toxicology Laboratory, Alberta Agriculture Food and Rural Development, and Canada Agriculture PFRA (Fitzgerald et al. 1997). It was found that arsenic concentrations in some private well waters in the Cold Lake area exceeded the Interim Maximum Acceptable Concentration (IMAC) of 25 µg/L in the *Canadian Guidelines for Drinking Water Quality* (Health Canada 1996). Local residents raised their concerns about high arsenic concentrations in their well waters during the Alberta Energy and Utilities Board Public Hearing into Imperial Oil Resources' Cold Lake Expansion project in 1998.

In response to these public concerns, an Alberta Health and Wellness Working Group was formed in 1998 to examine arsenic in groundwater in the Cold Lake area. The working group consisted of experts in medicine, environmental health, human risk assessment, arsenic speciation, water chemistry, clinical toxicology, biostatistics, hydrogeology, environmental engineering, and public health management. A review of the existing CAESA and other groundwater arsenic data indicated that the existing data were inadequate to allow a human health risk assessment to be conducted. Although there was no evidence of a widespread public health problem, it was nevertheless felt that a more rigorous survey of arsenic in groundwater was required.

A survey of arsenic in groundwater was conducted by Alberta Health and Wellness, the Lakeland RHA and the Trace Elements/Environmental Toxicology Laboratory, UAH with assistance from the Aspen RHA and the Keeweenaw RHA, between January 1999 and June 2000.

The objectives of this survey were to:

- measure arsenic concentrations in domestic well waters in the Aspen, Keeweenaw, and Lakeland RHAs;
- compare arsenic concentrations in groundwater across these regions;
- determine seasonal variation of arsenic concentrations in groundwater;
- conduct a human health risk assessment; and
- provide new information for public health management.

ARSENIC IN GROUNDWATER SURVEY

Materials and Methods

Sampling Locations

Three Regional Health Authority regions in Northern Alberta (Lakeland RHA, Aspen RHA and Keeweenaw RHA) were selected for sampling as shown in Figure 1.

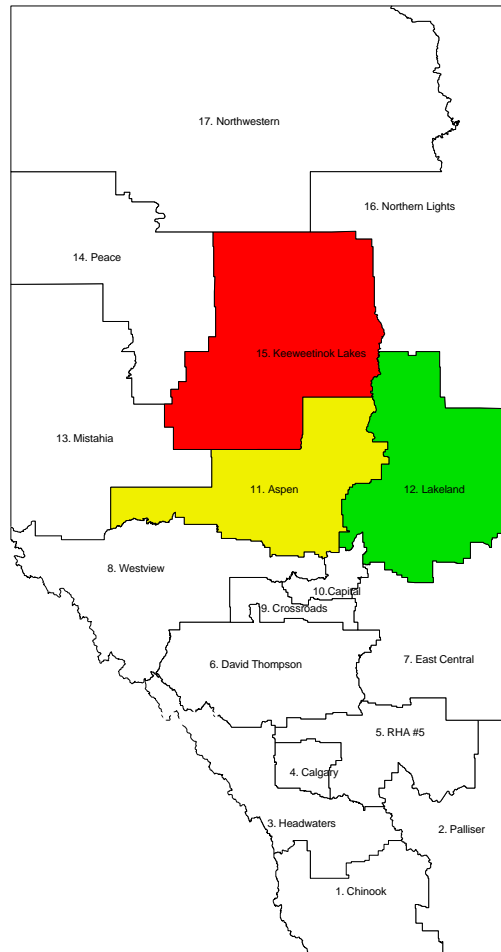


Figure 1 Locations of the Three Regional Health Authorities

Within the individual RHAs, local residents and businesses with private domestic wells were invited to participate in this survey. Some of the chosen sampling locations were based upon historical information collected during the CAESA Alberta Farmstead Water Quality Survey (Fitzgerald et al. 1997). All participants were chosen for their willingness to participate for the duration of the survey. The majority of the 59 sampling sites in Lakeland RHA were located to the west of Cold Lake in an area generally clustering around wells having historically high arsenic in their water. Six sites near St. Paul and Bonnyville were chosen based upon the CAESA survey results, three of which had high arsenic levels in their well water. Most of the 38 sampling sites in Keeweenaw RHA were located near the Slave Lake and High Prairie regions with one being a commercial plant site. The others were in areas north and northeast from Slave Lake. The 51 sampling sites in Aspen RHA were more randomly distributed within the RHA, generally centering on individual water well locations.

Raw tap water from private domestic wells that are used for human consumption and food preparation was collected from all but one site. Some raw water samples in offices, and camping sites were also collected. Treated water was collected from some private wells in order to compare concentration differences before and after water treatment. The most common sample location was the kitchen tap. Other sample locations included outside tap, pressure tank, basement/bathroom/laundry room tap, pump-house tap, camp holding tank or wash bay, well-head tap, and first aid tap.

The sampling period was 13 months in duration. In general, one raw water sample was collected from each well at each household each month. In some households, two or more raw water samples were collected from different wells with different depths or from one well with different water treatment methods. Sampling started in February 1999 and was completed in March 2000.

The geological formations forming the underlying bedrock differ from one RHA area to another. In figure 2, the sampling locations in the three RHA regions are combined with information obtained from the 1999 Geological Map of Alberta about these underlying bedrock geological

formations (Hamilton et al. 1999).

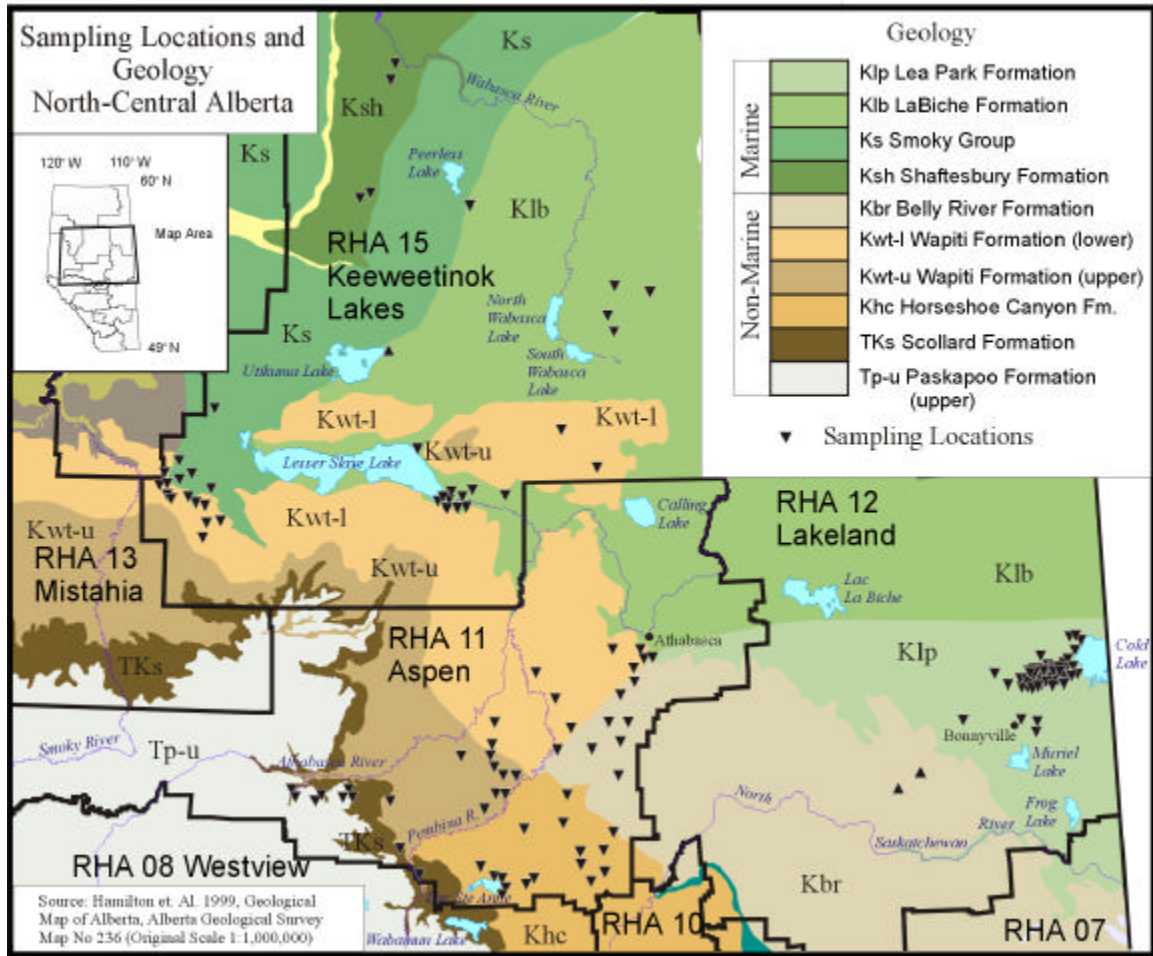


Figure 2 Sampled Well Sites by Underlying Bedrock Geological Formations

A brief description of these underlying bedrock geological formations and their symbols are listed in Table 1.

Table 1 Description of Geological Formations

Geological Formation Type	Geological Formation Name	Symbol	Description
Marine	LaBiche Formation	Klb	Dark grey shale and silty shale; ironstone partings and concretions; silty fish-scale bearing beds ; marine
	Lea Park Formation	Klp	Dark grey shale; pale grey, glauconitic silty shale with ironstone concretions; marine
	Shaftesbury Formation	Ksh	Dark grey fish-scale bearing shale; numerous nodules and thin beds of concretionary ironstone; bentonite partings; marine
	Smoky Group	Ks	Dark grey shale and silty shale, nodules and thin beds of concretionary ironstone; marine
Non Marine	Belly River Formation	Kbr	Grey to greenish grey, thick-bedded, feldspathic sandstone; grey clayey siltstone, grey and green mudstone; concretionary ironstone beds; nonmarine
	Horseshoe Canyon Formation	Khc	Grey, feldspathic, clayey sandstone; grey bentonitic mudstone and carbonaceous shale; concretionary ironstone beds, scattered coal and bentonite beds of variable thickness, minor limestone beds; mainly nonmarine
	Paskapoo Formation – upper	Tp-u	Grey to greenish grey, thick-bedded, calcereous, cherty sandstone; grey and green siltstone and mudstone; minor conglomerate, thin limestone, coal and tuff beds; nonmarine
	Scollard Formation	TKs	Grey felspathic sandstone, dark grey bentonitic mudstone; thick coal beds; nonmarine
	Wapiti Formation - lower - upper	Kwt-l Kwt-u	Grey, feldspathic, clayey sandstone; grey bentonitic mudstone and bentonite; scattered coal beds; nonmarine

Source: Hamilton *et. al.* 1999, Geological Map of Alberta, Alberta Geological Survey

The 59 sampling sites in Lakeland RHA encompass areas underlain primarily with marine shale formations, specifically the Lea Park Formation (97%). A small number are underlain by the Belly River Formation (3%) which is non-marine. The 51 sites in Aspen RHA encompass areas underlain primarily by non-marine formations, specifically by the Belly River Formation (18%), the Horseshoe Canyon Formation (33 %), the Paskapoo Formation (upper) (8%), the Scollard Formation (8%) and the Wapiti Formation (lower and upper) (31%). The remaining are underlain by the LaBiche Formation (2%), which is a marine shale formation. The 38 sites in Keeweenaw RHA are more evenly divided between marine and non-marine formations. The underlying marine formations include the LaBiche Formation (39%), and the Smoky Group (19%). The remaining sites are underlain by the Shaftesbury Formation (10%) and the Wapiti Formation (lower) (32%), which are non-marine formations.

Field Collection

Environmental health staff carried out the field collections from the domestic wells. After purging for 2 minutes, each sample was collected in a 500-ml PET500 (polyethylene terephthalate) trace metal free (TMF) sample bottle. The bottle was properly labeled for trace metal analysis with a unique sample identification number. The samples were collected at various points of time throughout the day. Each sample was immediately preserved with 5 ml TMF Nitric Acid, 70% (Eagle Picher^R 5-ml ampule-ACN-5 part #00505), the bottle was tightly capped and inverted several times to completely mix the sample. The sample has a final concentration of 0.5% HNO₃. All samples were kept cold ($\leq 4^{\circ}\text{C}$) prior to shipping. All samples were shipped to the Trace Elements/Environmental Toxicology Laboratory in Edmonton.

The following information was recorded during sampling: unique sample identification number, health unit, owner's name and address, legal land description, detailed well latitude/longitude position measured by Global Position System (GPS) (in Lakeland RHA only), well depth, water source, collection site, treatment methods and collection date and time.

Trace Element Analysis

Twenty-three trace metal elements were analyzed. These elements include arsenic, aluminum, antimony, barium, beryllium, boron, cadmium, chromium, cobalt, copper, iron, lead, manganese, molybdenum, nickel, selenium, silver, strontium, titanium, thallium, uranium, vanadium and zinc.

Trace metal analysis was performed using modified American Public Health Association (APHA) Standard Methods for the Examination of Water and Wastewater protocols. Samples were stored at 4⁰ C prior to analysis. Samples and standards were prepared in a trace metal free (TMF), positive pressure, hepafiltered room employing Eppendorff^R pipettes/ tips and SARSTEDT^R polypropylene sample tubes. SPEX^R Certified Ultra-pure single element standards, SEASTAR^R TMF concentrated HNO₃ acid and Barnstead^R 18 Megohm-cm TMF water were employed for the weight/weight preparation of all mixed aqueous calibration standards, internal standards and quality control samples.

The analyses were conducted in a separate TMF, positive pressure, hepafiltered room employing a PE-SCIEX^R Elan 6000 Inductively Coupled Plasma - Mass Spectrometer (ICP-MS) operating in the quantitative mode with internal standardization. All samples contained a mixed internal standard consisting of ⁴⁵Sc, ⁸⁹Y, ¹⁰³Rh, and ¹⁸¹Ta. The total recoverable metal by direct analysis for 23 trace metals was performed using a modified Ontario Ministry of Environment DWATER protocol (Determination of Trace Metals in potable waters by ICP-MS). The ICP-MS method employed was consistent with the principles outlined in the USEPA Method 200.8 (USEPA 1994) for a total recoverable analyte by direct analysis of an unfiltered acid preserved drinking water sample employing ICP-MS. Method Detection Limits were 1 µg/L for all measured elements except for iron (20 µg/L).

Internal/External Quality Assurance was conducted. Trace metal analytical procedures adhered to stringent in-house QC protocols employing standards and QC samples directly traceable to international standard reference materials. The analytical protocol typically consisted of 15-25% QC samples/unknowns. In addition, the accuracy and precision of the trace metal analyses were

concurrently further monitored employing the National Institute of Standards & Technology Standard Reference Material (NIST) for Trace Elements on Water (NIST SRM 1643d) employed as additional QC samples. Typical RSDs for the trace metals were between 1% and 3%. All analyzed NIST SRM 1643d samples were within acceptable certified values.

Further validation of the data quality was ensured by successful participation in two external Interlaboratory Proficiency Testing (PT) programs for all the parameters in this study. The first PT program was the biannual Alberta Water Analysts Committee PT program (25-35 Alberta water laboratories) and the second was the Analytical Product Groups (APG) WP Proficiency Testing Program (>250 North American laboratories) on a quarterly basis. Both PT programs meet the stringent International Standards Organization (ISO) Guide 43, Part I, 1996 Proficiency Testing Program protocols employing z-scores for performance evaluations. The APG program, the largest PT provider of water samples in North America, is ISO 9001 certified and they are accredited under the new NAVLAP/ NIST Proficiency Testing Program. In addition, their mean and standard deviation values are calculated as required by the US EPA National Standards for Water Proficiency Testing Program.

Statistical Analysis

A customized Oracle^R 7 PE Informatics SQL*LIMS^R database stored all demographic and analytical information about each sample. This included owner information, RHA of origin, well location (legal land description, latitude and longitude), well depth, date/time of sampling, collection site, type of sample (untreated or treated and type of treatment) and test results for each of the 23 trace elements. All relevant descriptive and analytical data from each sample site were retrieved from this SQL*LIMS^R DB using Oracle^R Browser. This data was placed into a separate electronic database where it was correlated to geological formation information. Statistical analysis on this data was conducted using SPSS^R (versions 6.1 and 10).

Results

Sampling Information

A summary of the information about the number and types of samples is presented in Table 2. A total of 149 households participated in the survey in three RHAs. A raw water sample was not available from one of the households. 135 of out 148 (91%) households completed at least 12 months of the sampling program between February 1999 and March 2000. 123 households completed 13 months of sampling. One domestic well per site was sampled in 140 households and two wells per site in 8 households. The well depths ranged from 11 to 573 feet. A total of 259 tap water sites were sampled, consisting of 156 raw water sites and 103 treated water sites. A total of 2817 samples were analyzed for arsenic and 22 other trace metals.

Table 2 Samples and Sample Types

Type of Sample	Regional Health Authority						Total	
	Aspen		Lakeland		Keeweenaw		Sample	Site
	Sample	Site	Sample	Site	Sample	Site		
Raw water – First well ¹	653	51	686	59	383	38 ³	1722	148
Raw water – second well ²	-	-	61	5	30	3	91	8
Treated – post iron filter	-	-	123	11	97	10	220	21
Treated – post softener	79	7	321	29	43	6	443	42
Treated – post carbon filter	1	1	23	2	24	2	48	5
Treated – post reverse osmosis	15	2	13	1	114	14	142	17
Treated – post chlorinator	-	-	-	-	37	4	37	4
Treated – post distiller	81	7	2	2	30	4	113	13
Treated – other	-	-	-	-	1	1	1	1
Total	829	68	1229	109	759	82	2817	259

¹ excludes 1 site where no raw water was taken.

² excludes 2 sites where only one sample was taken.

³ includes one commercial plant site.

Arsenic Concentrations by Regional Health Authority

Table 3 tabulates percentages of mean arsenic concentrations in raw and treated water samples categorized by regional health authority. Concentrations in excess of 25 µg/L were observed in 21.9% of raw water samples in the Lakeland RHA, 3.9% in the Aspen RHA and 19.5% in the Keeweenaw RHA. Arsenic levels exceeding 50 µg/L were found in 12.2% of raw water samples in the Keeweenaw RHA.

Table 3 Percentage of Average Arsenic Concentrations in Raw and Treated Water

As Conc. (µg/L)	Raw Water						Treated Water					
	<5	5-9	10-24	25-29	30-49	>50	<5	5-9	10-24	25-29	30-49	>50
Lakeland	39.1	10.9	28.1	6.3	15.6	-	37.1	20.3	26.8	5.8	9.8	0.2
Aspen	84.3	7.8	3.9	3.9	-	-	75	6.8	17.6	0.6	-	-
Keeweenaw	56.1	9.8	14.6	4.9	2.4	12.2	56.9	11.0	19.4	2.0	1.7	9.0

Seasonal Variation

Repeated-measures Analysis of Variance (ANOVA) was conducted to determine if arsenic levels varied within well water sites over months. The analysis indicated that there was no systematic temporal variation (F change = 1.54, $p > 0.05$) in arsenic levels. The analysis also revealed that the mean level of arsenic within a well water across all samples was an excellent summary of the data from monthly samplings ($r = 0.951$, $p < 0.0001$). Figure 3 illustrates this fit by showing the mean levels and variation around the mean arsenic levels due to monthly samples for each of the 140 raw water sample sites on which 6 or more samples were drawn. Further data analysis proceeded using mean levels for each sample site for all trace elements.

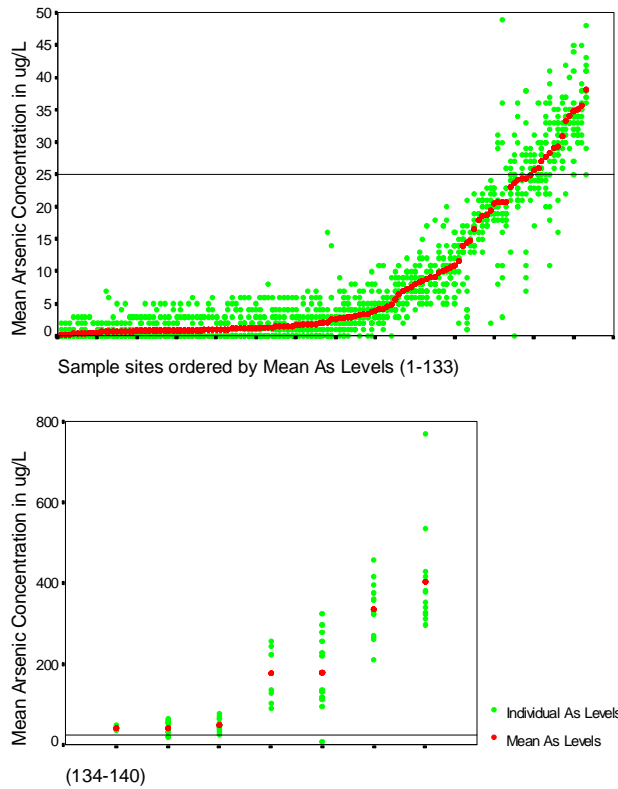


Figure 3 Mean Arsenic Levels and Monthly Variation by Well Site

Geographical and Geological Variation

Analysis of geographic and geological variation proceeded only with mean arsenic concentrations derived from wells from which 6 or more samples were taken. Figure 4 repeats information from figure 2 except that it excludes the sites of wells from which fewer than 6 samples were taken. The figure shows sites according to measured latitude and longitude and the underlying bedrock geological formation in which the well site was located.

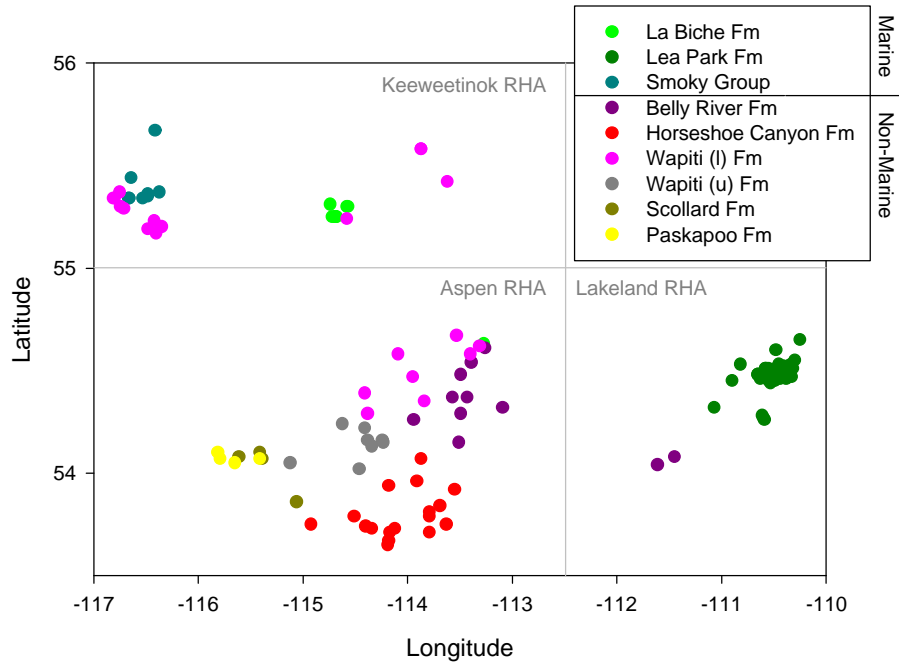


Figure 4 Sample Sites by Latitude, Longitude and Formation

The distributions of sample site mean arsenic levels for untreated water are shown in Figure 5. Within each of the major underlying bedrock geological formations, the mean arsenic concentrations for each well site are presented in order from lowest to highest concentration equally spaced along the horizontal axis with the concentration itself available from the vertical axis. This form of display allows the reader to abstract approximate information about the sample size for each formation type, the range of values within each formation, the presence or absence of extreme values, and the approximate averages and percentiles of the distributions within each formation. It also provides a visual comparison of these quantities across formations.

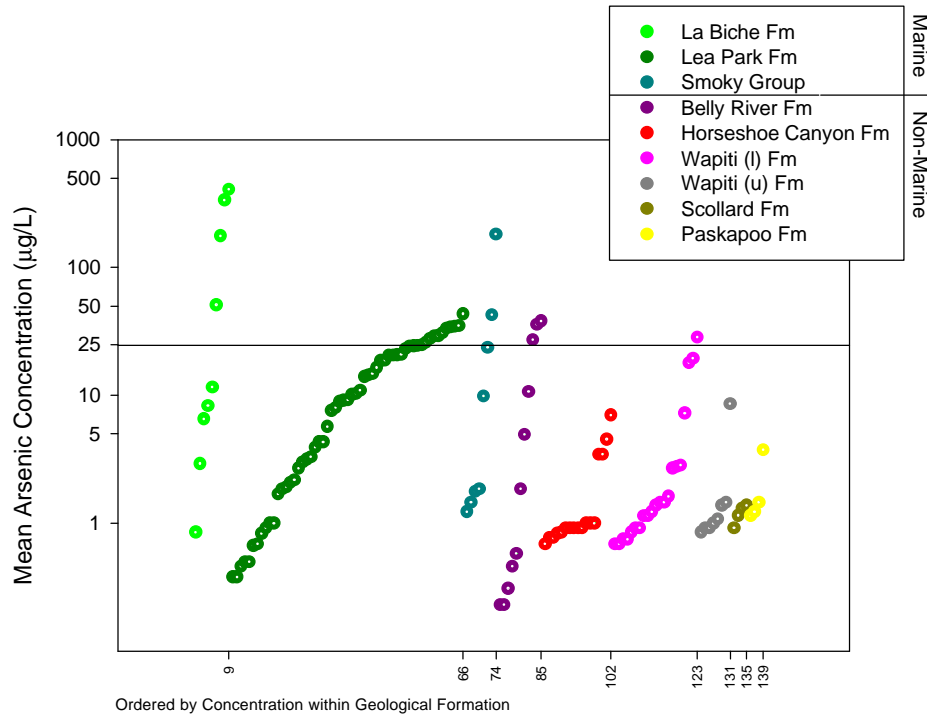


Figure 5 Distribution of Mean Arsenic Levels by Underlying Bedrock Formation

Analysis of Variance (ANOVA) confirmed that the differences in arsenic concentrations between the underlying geological formations apparent in figure 5 were statistically significant ($F= 58.4$, $df=8,2809$, $p<0.001$).

For this sample population, higher arsenic levels and greater numbers of levels above the guidelines are generally associated with areas underlain by the LaBiche, the Lea Park, and the Smoky Group Formations, all of which are marine formations containing shale. Three sample sites from the east of Slave Lake and one site from the west of High Prairie in areas underlain by the LaBiche Formation and the Smoky Group, respectively, contained very high levels of arsenic. Annual average concentrations of arsenic in these three sites ranged from 180 to 400 µg/L.

There were few high arsenic sample sites in regions underlain by non-marine geological formations. Three high arsenic sample sites (two in the northwest of St. Paul and one in the south

of Athabasca) were observed in areas underlain by the Belly River Formation. There is a possibility that these may have arisen due to local heterogeneity in geological substrates (e.g.channels) that may provide some connection to adjacent marine shale bedrock. Annual average arsenic concentrations ranged from 27 to 38 $\mu\text{g/L}$ in these three sites. The single elevated sample site (27 $\mu\text{g As/L}$) from the area underlain by the lower Wapiti Formation north of Barrhead may also be an anomaly as there is no geological similarities to the areas with underlying marine shale bearing formations. All of these higher arsenic sites may also influenced by local hydrogeological influences not considered here.

Figure 6 repeats Figure 5, but here the colour coding indicates the depth of the well.

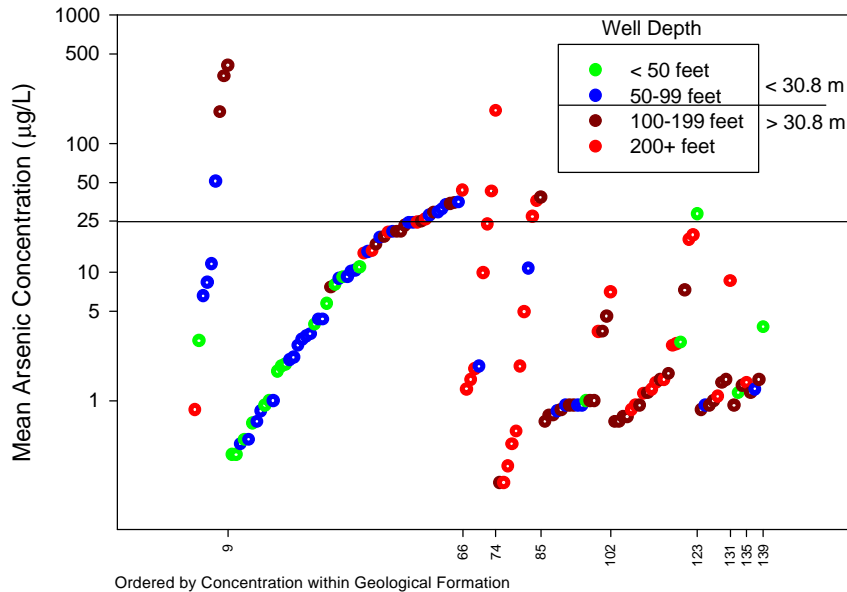


Figure 6 Distribution by Well Depth within Geological Formation

The notable finding illustrated by this figure is that all elevated arsenic levels were associated with wells deeper than 50 feet (with a single exception in the Wapiti Formation).

One way to summarize these findings is to aggregate the formations into two groups: non-marine formations and marine formations; and within the marine formations, to categorize the well depths

into shallow (less than 50 feet) and deep (50 feet and over) categories. Figure 7 shows the mean arsenic concentration distributions for this categorization.

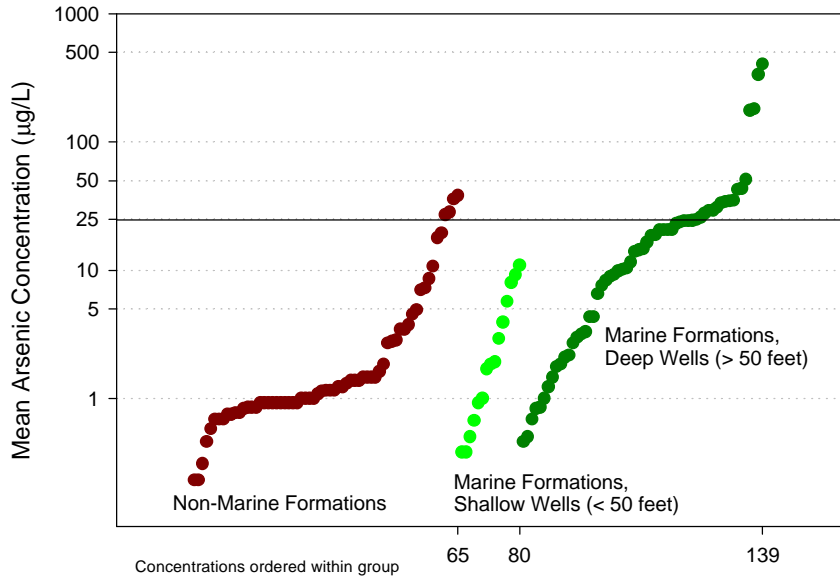


Figure 7 Distribution of Mean Arsenic Levels by Category of Underlying Formation and Depth of Well

In the non-marine formations, 6% of well sites had mean arsenic levels exceeding 25 µg/L, while in the Marine formations, the corresponding figure for shallow wells was 0% and for deep wells it was 27.3%. The difference is statistically significant (Kruskal-Wallis non-parametric ANOVA, Chi-Square = 5.09, df = 2, p<0.001). The central tendency of the mean arsenic levels (median of 1.15 µg/L for non-marine formations, median of 1.85 µg/L for marine formations with shallow wells and median of 14.71 µg/L for marine formations with deep wells) also differs significantly (Kruskal-Wallis non-parametric ANOVA, Chi-Square = 41.48, df = 2, p<0.001).

Associated Trace Elements

In order to examine the joint distribution of trace elements within the well waters of this sample population, a multivariate analysis was undertaken. All trace element levels were logarithmically transformed and standardized to a mean of 0 and a standard deviation of 1, and a factor analysis of the intercorrelations between trace element distributions was conducted. The results are represented in a biplot. A biplot is a generalization of a scatterplot and shows a two dimensional representation (or ordination) of complex multivariate data.

Figure 8 is a biplot representation of the relationships between levels of the trace elements (represented by their chemical abbreviations) as well as the patterns of these trace elements across sample sites within areas underlain by specific bedrock geological formations (represented by their geological symbols from Table 1). Since the primary focus was on arsenic levels, these two factors were chosen from the factor analysis to maximize the accuracy of the reproduction of arsenic levels. In this figure, the trace elements are represented in red or pink, the symbols for the areas underlain by marine bedrock geological formations containing shale are shown in green, and the symbols for the areas underlain by non-marine bedrock geological formations are shown in gray. The origin point of the graph, which is important in interpretation is marked with a + sign at the centre of the representation.

The relationships between trace elements are represented by the angle between vectors drawn from the trace element symbol to the origin. Higher correlations across the data as a whole are represented by smaller (more acute) angles and no relationship is indicated by an angle of 90 degrees. In addition, the extent to which the full variability of a trace element is captured in this two dimensional rendering is indicated by the length of the vector. The longer the vector, the greater is the extent to which that variability has been captured. As mentioned above, the current representation was chosen to maximize the length of the vector associated with arsenic.

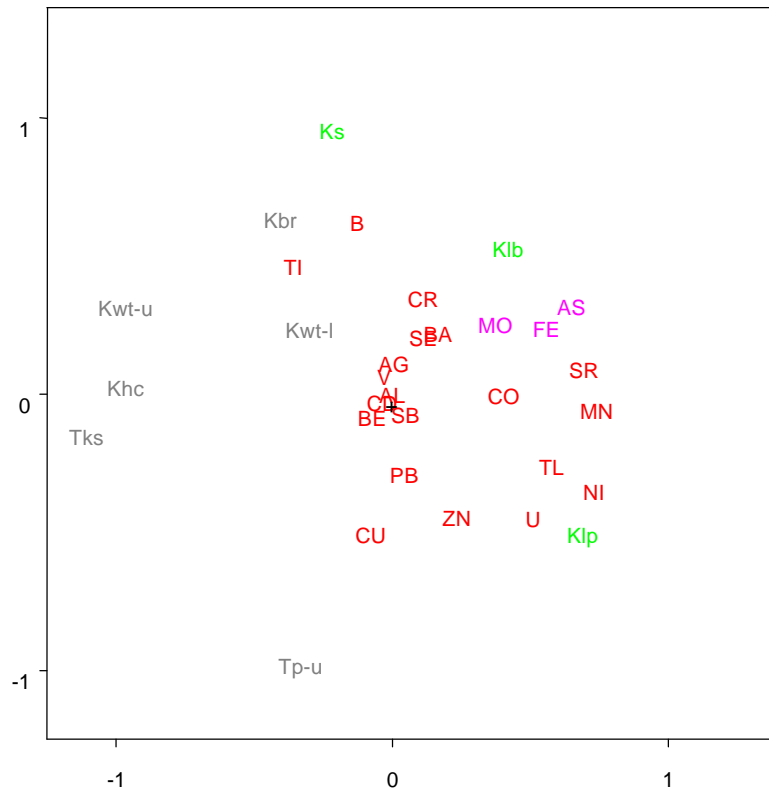


Figure 8 Biplot of Relationships among Trace Elements and Underlying Bedrock Geological Formations

Examination of the cluster of trace element locations in the biplot indicates relatively strong correlations between levels of arsenic, iron, and molybdenum (shown in pink) and weaker correlations between arsenic levels and levels of other trace elements.

The positions of the points labeled with the geological formation symbols are used to represent the average trace element profiles in relation to the overall mean profile in the areas underlain by these geological formations. To retrieve the pattern of trace elements for each region requires that a vector be drawn from the geological symbol point to the origin. When the points representing the trace elements are projected perpendicularly to this vector, the resulting ordering is a representation of the ordering of the trace element levels on the average profile for the area underlain by the specific geological formation. Since the data was standardized in this sample,

these orderings represent relative differences referenced to the entire set of samples as a whole and not to absolute levels of the trace elements.

In addition, the longer the vector, the larger the differences among the trace elements in a particular profile. Thus for the Belly River Formation (Kbr), the relatively higher trace elements are boron and titanium, and the relatively lowest are nickel and uranium. Since this vector is relatively long, the differences between the relative levels of these trace elements and the relative levels of other trace elements in the ordering are large. The vector for LaBiche Formation (Klb) is shorter, but the procedure described above does show that LaBiche Formation and the Lea Park Formation have higher relative levels of arsenic. The other geological formations have arsenic between the middle and the bottom of the relative ordering by the same procedure.

An important finding from this representation is that the sample sites underlain by marine shale formations (in green) are separated in the representation from those underlain by non-marine formations (in gray). In general, the sites underlain by marine formations have higher levels of arsenic (as previously described) but also tend to have higher levels of iron and molybdenum as well. Within the marine formations, the Smoky Group, the Lea Park Formation, and the LaBiche Formation appear to have different profiles of trace elements. The Smoky Group is associated with relatively higher levels of boron and titanium, while the Lea Park formations are associated with relatively higher levels of nickel, thallium, uranium and zinc. The LaBiche formations show an intermediate pattern but show the highest relative differences for arsenic.

In summary, the biplot indicates that higher levels of arsenic are associated with higher levels of iron and molybdenum in this set of samples. The areas underlain by the marine shale formations (Smoky Group, Lea Park, and LaBiche Formations) are associated with higher levels of arsenic and iron than the other underlying geological formations. A summary of the mean and median concentrations for 23 trace metals is listed in Table 4.

Table 4 Annual Average Concentrations (µg/L) of Trace Elements

Compound ^a	Regional Health Authority						Canadian Drinking Water Guidelines (1996)	
	Aspen		Lakeland		Keeweenaw		Value	
	Median	Mean	Median	Mean	Median	Mean		
Aluminum	8.1	16.1	8.5	17.7	10.3	48.3		
Antimony	0.2	0.5	0.3	0.4	0.2	0.9		
Arsenic	1.1	3.5	7.9	12.5	2.8	27.9	25	IMAC^c
Barium	49.9	95.2	38.4	80.1	55.0	214.6	1000	MAC ^b
Beryllium	Nd	0.5	0.1	0.1	0.2	0.5		
Boron	247.2	332.9	186.1	214.1	211.0	326.3	5000	IMAC
Cadmium	Nd	Nd	nd	Nd	nd	0.1	5	MAC
Chromium	10.9	10.4	9.8	9.6	6.0	6.4	50	MAC
Cobalt	Nd	Nd	nd	0.2	nd	0.3		
Copper	12.8	31.1	6.0	34.7	9.7	55.1	1000	AO ^d
Iron	134.2	512.2	880.9	1969.7	705.1	2381.3	300	AO
Lead	0.4	1.3	0.2	2.2	0.5	3.5	10	MAC
Manganese	14.2	73.6	95.9	174.9	68.5	138.1	50	AO
Molybdenum	2.5	2.7	4.5	6.3	2.0	4.4		
Nickel	0.9	1.4	3.0	3.4	2.4	4.2		
Selenium	0.1	1.0	0.2	0.7	0.1	0.2	10	MAC
Silver	Nd	Nd	nd	Nd	nd	2.8		
Strontium	136.9	261.9	328.0	351.2	229.7	432.7		
Titanium	0.7	1.4	nd	Nd	1.0	2.6		
Thallium	Nd	Nd	1.7	2.0	nd	0.1		
Uranium	Nd	0.6	1.7	4.9	nd	0.6	100	MAC
Vanadium	Nd	Nd	nd	Nd	nd	0.1		
Zinc	23.1	52.7	30.3	1027.2	57.0	404.6	5000	AO

^a Limit of quantitation was 1 µg/L except for iron (20 µg/L). nd = non-detectable.

^bMAC = Maximum Acceptable Concentration.

^cIMAC = Interim Maximum Acceptable Concentration.

^dAO = Aesthetic Objective.

Water Treatment

The effects of any form of water treatment on mean arsenic levels for samples from areas underlain by the Smoky Group, the Lea Park, the Belly River, and the LaBiche geological formations are illustrated in Figure 9. Arsenic levels in treated well waters in these regions were lower than those in raw well waters (Figure 9).

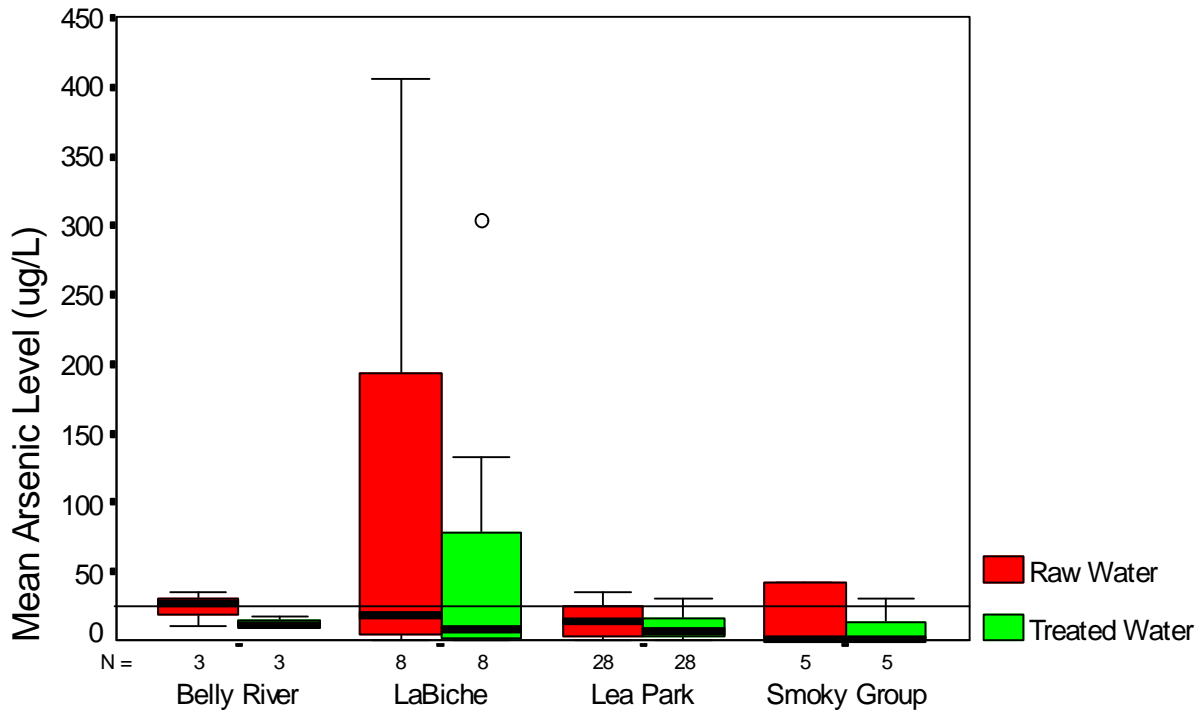


Figure 9 Arsenic Levels for Treated and Untreated Water

Note: A site includes at least 6 raw and at least 6 treated levels. The median is represented by the line through the middle of a box. The 25th and 75th percentiles are the upper and lower edges of a box. The notched lines designate the 95th percentile and, where possible, the 5th percentile. The symbol indicates an outlier, a statistical value far removed from the rest of the distribution. The guideline of 25 $\mu\text{g/L}$ for arsenic is also represented by a line.

Analysis of Variance reveals that the differences of arsenic levels between treated and untreated water samples are statistically significant. It should be noted that a proportion of treated water samples still remain above the recommended guideline. The small numbers and unequal distributions of types of water treatment do not allow strong statistical conclusions to be drawn

about their differential effectiveness.

Examination of the treatment data from all sites indicated, as expected however, that carbon filtration appears not to reduce arsenic levels and that, in general, neither do softeners (only 14% of softener sites lowered arsenic values while 1 softener increased the arsenic values). Forty percent of the iron-filtered sites were associated with arsenic reductions while one third of the reverse osmosis and distiller sites had lower arsenic values. One third of the distiller samples significantly raised the lead levels and 60% significantly raised the copper levels.

EXPOSURE AND POTENTIAL HEALTH RISK

Arsenic Sources and Concentrations in Groundwater

Arsenic is widely distributed in nature. It is a common constituent in sedimentary and igneous rocks. The estimated arsenic concentration in the upper earth crust ranges from 1.5 to 5 mg/kg (Taylor and McLennan 1985). Organic arsenic, which is combined with carbon, hydrogen or oxygen, is usually found in plants, animals and most food. Inorganic arsenic, which is combined with oxygen, chlorine or sulfur, is usually found in the water, soil and air.

Arsenic in drinking water can result from either man-made or natural sources. The major human-activity related sources include agricultural uses (pesticides application), wood preservatives, mining and smelting, burning fossil fuels and wastes, and glass, paper and cement manufacturing. The natural sources of arsenic are from mineral formations containing pyrites and related sulfide minerals, geothermal activity, and volcanic activity. Arsenic is commonly present in primary sulfide minerals such as arsenic pyrites, realgar, lollingite and orpiment and many mineral species such as gold, copper, lead and silver (Peters et al. 1999, USEPA 2000).

In this study, arsenic concentrations were elevated in the areas underlain by the LaBiche, the Lea Park, and the Smoky Group Formations. These underlying bedrock geological formations contain marine shale deposits that frequently also contain pyrites. Pyrites in such deposits are known to be enriched with arsenic. There were three high arsenic sites in areas underlain by the Belly River Formation near northwest of St. Paul and south of Athabasca. There is a possibility that these may have arisen due to local heterogeneity in geological substrates (e.g. channels) that may provide some connection to adjacent marine shale bedrock.

Arsenic was positively correlated with iron level in groundwater in some geographic areas (USEPA 2000). In the sample population of this survey, elevated arsenic levels in groundwater

were generally related to areas underlain by a number of specific bedrock geological formations and higher iron levels in groundwater.

Groundwater flowing through underlying sedimentary formations and soil can scavenge out arsenic that is present as a trace contaminant. Groundwater normally contains higher concentrations of inorganic arsenic than are found in surface water. The typical average total arsenic concentrations in natural water in Canada range from 1 to 2 µg/L. Most Canadian ground waters contain arsenic less than 50 µg/L (CEPA 1994). The data in this survey are consistent with the Canadian findings.

Arsenic levels in groundwater vary among different geographic areas. High arsenic concentrations up to 11,000 µg/L were found in some areas of Ontario, Quebec, New Brunswick, Nova Scotia and British Columbia. Such higher arsenic concentrations were often found in groundwater in the vicinity of primary sulfide and gold mining areas, heavy pesticide application areas, and wood preservative facilities (CEPA 1994, Peter et al. 1999).

In summary, the elevation of arsenic concentrations in groundwater in this survey is generally associated with areas underlying specific bedrock geological formations contain marine shale deposits and depth of well in the three RHA areas of Northern Alberta. Marine shale deposits frequently contain pyrites that are known to be enriched with arsenic. No seasonal variation was observed. The findings indicated that the elevated arsenic levels, on average, in Northern Alberta are likely to be attributed to natural processes.

Treatment Technology

The USEPA has reviewed technologies available for the removal of arsenic in drinking water (USEPA 2000). Most treatment technologies are used in large public water supply systems. Options to reduce arsenic exposure from groundwater in a household include obtaining another supply with lower arsenic levels or treating the current supply to lower the arsenic levels¹.

In some households participating in this survey, water samples pre- and post- treatments were taken. Water treatment refers to systems that reduce harmful contaminants and improve water conditions such as taste, color, odor, hardness and corrosiveness. The major household treatment methods presented in this survey consist of one or a combination of softener, activated carbon filters, oxidation filters (e.g. iron filters), distillers and reverse osmosis devices.

The primary functions of some treatment devices do not include arsenic reduction. For example, activated carbon filters are primarily intended to remove taste, odour, chlorine, some pesticides, and large particles. Activated carbon filters will not remove bacteria, dissolved metals, chlorides, nitrates, or fluorides.

Softeners and iron filters are used to control bacteria in the well. Softeners are intended to remove hardness causing elements such as calcium and magnesium. Oxidizing filters are primarily used for removal of iron, manganese and hydrogen sulfide. Certain iron filings can remove arsenic when treating high influent arsenic levels.

Distillers are used for disinfection to control bacteria, removal of nitrates, dissolved salts, sulfates

¹ People who use drinking water from a private well may install water treatment devices at the point of use (POU) or at the point of entry (POE) (Goodrich et al. 1992, Lykins et al. 1992). POU devices treat water from a specific tap such as a faucet. The water is typically only used for drinking and cooking. POE units treat water entering a whole house system. This water is typically used for bathing/showering and laundry as well as for drinking and cooking.

and carbonates of sodium, potassium and magnesium, and organic matter. Distillers may remove arsenic in drinking water. Reverse Osmosis (OR) filtration system for home water treatment will decrease dissolved minerals like nitrate, sulfate, calcium, magnesium, potassium, fluoride, silica, boron and bicarbonate, trace metals including arsenic and other conditions such as taste and odour. Reverse Osmosis can remove arsenic efficiently (greater than 95%) if water recovery is optimized.

Ion exchange can effectively remove arsenic for groundwater systems with low sulfate and total dissolved solids content and as a polishing step after filtration. Activated alumina filter can effectively remove arsenic in water with high total dissolved solids and at high pHs.

As seen from the data in this survey, carbon filters and softeners did not effectively remove arsenic. Selected treatment technologies such as iron filters, reverse osmosis and distillers in some instances could effectively and efficiently lower arsenic levels but this depends on many factors. The operation and maintenance of some treatment devices will and did influence the effectiveness and efficiency of reduction of arsenic. In a couple of instances the arsenic levels actually rose for one sampling cycle. Hence, caution was used to interpret the arsenic levels resulting from pre- and post- treatment in households because many control factors, such as appropriate operation and maintenance of treatment devices, were not collected in this survey. Many treatment devices in many households were installed for water conditioning and elimination of biological and chemical contaminants other than arsenic reduction. The only way to ensure a specific treatment device effectively lowers the arsenic levels is to have the sample analyzed pre and post treatment.

Exposure

The general population is exposed to low levels of arsenic through water, food, air and soils. Food is a major arsenic source for people. Arsenic is abundant in seafood, meat and poultry (Dabeka et al. 1993, Seiler et al. 1994). About 75% of the intake of arsenic comes from food, particularly seafood and fish. People are mainly exposed to arsenic via ingestion of food and

drinking water. A typical Canadian intake of the total arsenic from all sources for adults was 38.5 µg/day (Dabeka et al. 1987, 1993). The intake of inorganic arsenic from food was estimated to be 12.5 µg/day for males and 8.1 µg/day for females in Canada (Yost et al. 1998). Intake of arsenic via inhalation is negligible.

The median of arsenic levels in the three RHAs ranged from 1 to 8 µg/L. If local residents consume 1.5 L water, on average, per day, the intake of arsenic from domestic well water was estimated to be less than 12 µg /day. This survey showed that the average intake of inorganic arsenic for the majority of residents who use water from domestic wells in these three RHAs, especially in the Aspen region, was within the range of a typical Canadian intake. About 20% of the surveyed residents were exposed to relatively higher level of arsenic from drinking water as compared to the residents who use public water supply systems which contain arsenic at or below the *Canadian Drinking Water Guideline*. However, such intake levels of arsenic are considerably lower than doses that cause adverse health effects reported in the scientific literature.

Health Effects

Arsenic exists in many forms. The primary organic forms of arsenic presented in fish and seafood are less harmful to humans and are also rapidly metabolized and excreted from human body (Malachowski 1992, Seiler et al. 1994, Vahter 1994, Le 1999). For example, the most predominant arsenic species in lobster and shrimp is arsenobetaine. If people consume 250 grams of lobster or shrimp from a single meal, the intake rate of total arsenic could be 5,000 µg (Le 1999). But it would not cause harm to humans because arsenobetaine will be rapidly excreted via urine. In fact around 56-85% of seafood arsenic is excreted in the urine within 5-7 days (Seiler et al. 1994). There are other forms of organic arsenic in food that may pose some risks. However, there has not been enough research to accurately characterize the exposures and potential health risk from these other food sources. Thus, exposure to arsenobetaine from food was not a focus of the current human health risk assessment.

The most toxic arsenic species are arsenite (As III) and arsenate (As V). These two species are the most predominant compounds in groundwater. The majority of the reported adverse human health effects associated with arsenic resulted from drinking groundwater (Tseng et al. 1968, Wu et al. 1989, Chen and Wang 1990, Seiler et al. 1994, Guo et al. 1997, Hopenhayn-Rich et al. 1996 and 1998, Smith et al. 1998, Cuzick et al. 1992, Tsuda et al. 1995, Chiou et al. 1995, Bates et al. 1995). A number of studies conducted in several countries outside of North America reported an established relationship between skin and internal cancers and arsenic in drinking water at very high concentrations (several hundred $\mu\text{g/L}$) (Tseng et al. 1968, Wu et al. 1989, Chen and Wang 1990, Guo et al. 1997, Hopenhayn-Rich et al. 1996 and 1998).

These epidemiological studies have been able to establish a convincing case that exposure to such very high levels of arsenic in drinking water contribute to excess levels of skin and bladder cancers (NRC 1999). However, obtaining direct evidence of cancer risk from lower levels of arsenic exposure is very difficult. Large human populations would have to be studied to detect the small numbers of excess cases of cancer that would be predicted for lower level arsenic exposure in order to generate any statistical confidence in the study results. These studies would also have to be conducted over many years to be able to detect the small numbers of predicted cancer cases over lifetime exposure to low levels of arsenic. Because of these practical limitations, no epidemiological studies have been done to assess cancer risks at arsenic exposure levels of less than $50 \mu\text{g/L}$, the standard that has been in place under the U.S. Safe Drinking Water Act regulations (NRC 1999).

A high level of arsenic can cause several non-cancer effects. Chronic arsenic poisoning commonly shows skin lesion as the hyperpigmentation and hyperkeratoses characteristic. Hyperpigmentation was observed at lower exposure levels of greater than $10 \mu\text{g As/kg}$ body weight per day, a dose that would still correspond to about $500 \mu\text{g/L}$ in drinking water at typical consumption levels (NRC 1999). With acute or sub-acute exposure to inorganic arsenic in the range of several milligrams to grams daily, adverse effects on gastrointestinal system, cardiovascular, and nervous systems were observed in humans.

Although there is general consensus about the health risk posed by arsenic in drinking water at the very high levels that have been studied, there is no direct evidence to base risk estimation for levels of arsenic at or below current drinking water guidelines or standards. This is an area of intense interest in the scientific community and research is continuing into ways to better understand the risk posed by lower level arsenic exposure. However, definitive answers are not likely to be available in the near future.

Arsenic Risk Assessment

This health risk assessment of the arsenic is focused on cancer risk. The practice in cancer risk assessment has been to estimate an excess lifetime cancer risk. The process has come under increasing scrutiny in the past decade because of the widening recognition that the basis for cancer risk assessment at low exposure levels is highly uncertain, and that numerical estimates of cancer risk may be misleading if they are taken as being absolute numbers of expected cancer cases (Hrudey 1998). The intent of quantitative cancer risk assessment is to estimate an upper bound value of the plausible cancer risk for the overall population. The uncertainty in doing this is supposed to be captured by intentionally erring on the side of caution, that is, overestimating rather than underestimating the possible risk. As a result, the estimates that are produced must be seen as the maximum values that are realistic, but true values may be much lower and may be zero. Historically, many regulatory agencies set upper end values of lifetime cancer risk in the range of 10^{-4} to 10^{-6} . These levels mean that the chance of developing cancer would be no more than one person in ten thousand to one person in one million exposed persons over the course of an entire lifetime (taken as 70 years).

Health Canada with the Federal Provincial Territorial Committee on Occupational and Environmental Health continually develops Guidelines for Canadian Drinking Water Quality (Health Canada 1996). These guidelines currently have an interim maximum acceptable concentration (IMAC) of 25 µg/L for arsenic. This guideline was based primarily on the increased

incidence of skin cancer in the Taiwanese population (Health Canada 1992). For most Canadian populations, arsenic concentrations in drinking water are more than 170 times less than the concentration associated with a 5% increase in skin cancer in Taiwan (Abernathy et al. 1996). An excess lifetime cancer risk is calculated to estimate the potential health risk for the general population resulting from exposure to arsenic. The current IMAC was labeled interim because a high level of uncertainty was involved in the arsenic risk assessment process.

Table 5 Estimate of Excess Lifetime Skin Cancer Risk Associated with Arsenic

As Concentration in drinking water (µg/L)	Risk Level (70 yr lifetime)	Comment
5.00	1.8×10^{-4}	
10.0	3.6×10^{-4}	
25.0	9.0×10^{-4}	37.5 µg/d (1.5 l/d) Canada

The risk levels corresponding to the arsenic concentrations in drinking water are illustrated in Table 5. The estimated lifetime cancer risk associated with drinking arsenic-containing water at this IMAC is 9.0 in 10,000. This means that the *maximum plausible number* of people in a hypothetical population of 1,000 people who would develop cancer if they all consumed 1.5L of arsenic-containing water at a level of 25 µg/L every day throughout their lifetime (70 years) would be about 1 person (0.9). If a larger population were exposed, the maximum plausible number would be correspondingly higher (e.g. a maximum of 9 cancer cases possible in 10,000 exposed for a lifetime). We can not know the exact number because we cannot perform an experiment on human subjects for practical and ethical reasons. However, the process for estimation insures that the number would not be more than indicated, that it is likely to be less, and that it could be zero.

The above risk estimates reflect the development of skin cancer. Few skin cancer cases result in death and only 1% to 14% of arsenic related skin cancers are fatal. A comparison of death risk from various causes is listed in Table 6. The risk from drinking arsenic-containing water is estimated to be over 1500 times less than that from smoking, and over 15 times less than that from breathing second-hand tobacco smoke.

Table 6 Premature Risk from Various Causes

Cause	Voluntary (V) / Involuntary (I)	Lifetime risk of premature death (per 100,000)
Smoking (all causes)**	V	21,900
Smoking (cancer only)**	V	8,800
Motor vehicle	I	1,600
Frequent airline passenger	V/I	730
Coal mining accidents	I/V	441
Indoor radon**	V/I	400
Motor vehicle – pedestrian	I	290
Environmental tobacco smoke/living with a smoker**	I/V	200
Diagnostic X-rays**	I	75
Cycling deaths	I/V	75
Skin cancer by drinking arsenic-containing water at 25 µg/L**	I	12.6*
Lightning	I	7
Hurricanes	I	3

Source: Darnay (1992)

* based on 14% fatal rate of skin cancer at a risk level of 9×10^4

** indirect risk estimates - more uncertain than risks where the cause of death is not in doubt (Thomas and Hrudey 1998). Of these indirect risks, the smoker's risk estimates are the most certain because of the large population base and extensive research to establish the link between smoking and various causes of death.

Whether arsenic in drinking water causes adverse health effects depends upon four factors: exposure level, time frame, consistency and differential diagnosis. Some medical problems may appear only after exposure to certain levels of arsenic in drinking water. Adverse health effects associated with different levels of arsenic exposure are illustrated in Table 7.

**Table 7 Adverse Health Effects after Continuous Exposure
to Inorganic Arsenic in Drinking Water**

Exposure Level	Dose $\mu\text{g}/\text{day}$	6 months to 5 years		5 to >15 years	
		Effect	Increased Risk	Effect	Increased Risk
High	\uparrow	Death	Probable		
		Systemic problems*	Probable	Systemic problems	Probable
		Skin lesions	Unlikely	Skin lesions	Probable
	> 1 500	Cancers	Possible	Cancers	Probable
Moderate	1 500	Death	Unlikely		
		Systemic problems	Possible	Systemic problems	Probable
		Skin lesions	Unlikely	Skin lesions	Probable
	500	Cancers	Possible	Cancers	Probable
Low	500	Death	Unlikely		
		Systemic problems	Unlikely	Systemic problems	Unlikely
		Skin lesions	Unlikely	Skin lesions	Unlikely
	300	Cancers	Unclear, Possible	Cancers	Unclear, Possible
Very Low	?	Cancers	uncertain	Cancers	Uncertain, but expected to be less than a 1 in 1000 lifetime chance

Sources: Kosnett, M.J. (1998), ATSDR (1997), NRC (1999)

* Systemic problems include anemia, nervous system, GI problems, heart problems, lung problems, kidney problems and liver problems.

These doses causing health effects should be compared with the dose of 37.5 $\mu\text{g}/\text{d}$ that would arise from consuming 1.5L of drinking water meeting the Canadian Drinking Water Guideline IMAC of 25 $\mu\text{g}/\text{L}$. Some arsenic-related problems such as skin lesions may occur after several years of moderate or high level arsenic exposure and disappear several months to years after the

arsenic exposure ceases. Arsenic-related signs and symptoms are often consistent with the other known effects. The characteristic patterns of skin lesions like hyperpigmentation, progressing to hyperkeratoses, may be accompanied by other clinical evidence such as anemia gastrointestinal complaints and sensory predominant peripheral neuropathy.

The USEPA proposed a new Maximum Contaminant Level (MCL) of 5 µg/L for total arsenic in drinking water in May 2000. The endpoint used for this risk assessment is bladder cancer (USEPA 2000). The proposed standard would fall within the risk range of 10^{-4} . USEPA would not have non-community systems such as private wells comply with this proposed MCL but would require that individual owners monitor arsenic levels in their private wells.

As the USEPA and Health Canada stated (USEPA 2000, Health Canada 1992), there is uncertainty in the estimation of bladder or skin cancer risks. These uncertainties are dealt with by adopting the precautionary approach of intentionally estimating the highest level of risk that might apply rather than attempting to estimate the most likely level of risk (Hrudey 1998). Although the most likely risk level would certainly be more useful, the evidence available for making risk estimates does not allow a meaningful estimate of the most likely risk. A number of conservative assumptions are used in the arsenic risk assessment. The major sources of uncertainties include the following:

- Selection of endpoint and population. Selection of different types of cancers (e.g. skin cancer, bladder cancer or lung cancer) as endpoints would result in various estimates of cancer risk. For example, only small proportions of skin cancer associated with arsenic exposure are fatal. Northern American population studies did not report an association between cancers and arsenic in drinking water.
- Lack of the exact individual exposure in the study populations. Exposure assessment in the published epidemiological studies focused on historical data and well water data. In this case, no exposure of individuals was estimated.
- Geographic variation. The study population in rural Taiwan has different lifestyle and

dietary habits compared to the North American population.

- Lack of understanding of the dose-response relationship. The estimated cancer risk was based on extrapolation of response from high dose to low dose. The mechanisms by which arsenic causes cancer in humans are not fully understood, but it is entirely possible that low level arsenic exposures do not pose as much risk as is predicted by extrapolating risk estimates from the cancer observations at high dose levels.
- Lack of understanding of multiple chemical involvement. In most studies, multiple chemicals were measured from drinking water samples. Whether other chemicals cause cancers in the study populations was not fully understood.
- There are some indications that nutrition may play an important role in cancer occurrence from arsenic exposure, with cancers more likely to occur in those who are malnourished.
- Choice of mathematical models. Estimated cancer risk relies on the use of mathematical models. The use of different models would result in different estimated risk values, although a recent analysis of this issue produced a variety of upper bound estimates that were roughly comparable for risk predictions near 10 $\mu\text{g/L}$ (NRC 1999).

The estimated arsenic cancer risk applies to the general population as a whole. Individual risk can vary widely. Many factors will affect individual risk associated with drinking arsenic-containing water. These include variability among individuals (susceptibility), dietary habits, duration of exposure, amount of consumption of arsenic from drinking water, health condition, and others. The ‘true’ cancer risk associated with arsenic in drinking water cannot be known with confidence at this time, but available risk estimates are most likely cautious estimates of the maximum plausible risk.

CONCLUSIONS

The survey indicated that 96% of domestic well water in the Aspen RHA and 80% of well water in the Lakeland and Keeweenok RHAs contains arsenic at or below 25 µg/L, the Interim Maximum Acceptable Concentration in Canada. About 12% of well water in the Keeweenok RHA contains arsenic in excess of 50 µg/L. In general, groundwater contains relatively higher concentrations of arsenic than surface water. The results from this survey are consistent with the Canadian findings that most Canadian groundwater contains arsenic less than 50 µg/L.

Elevated arsenic concentrations were most likely to be observed in water from domestic wells greater than 50 feet in depth and associated with areas underlain by three marine bedrock geological formations - the LaBiche, the Lea Park, and the Smoky Group. Constituents of these formations contain arsenic-enriched materials such as pyrites. Analysis of trace elements indicates relatively strong relationships between levels of arsenic and iron and between arsenic and molybdenum in areas underlain by these formations. These results are consistent with findings in the scientific literature and suggest that the elevated arsenic levels in Northern Alberta, in general, are attributable to natural processes.

The average intake of arsenic from domestic well waters for the majority of residents in these three RHAs falls within a typical Canadian intake of arsenic via ingestion. Some local residents intake more arsenic from well waters than the residents who use the public water supply system. However, the average intake levels of arsenic are considerably lower than doses that cause adverse health effects as reported in the scientific literature.

The guidelines and standards for arsenic in drinking water from various regulatory agencies were developed for large public water supply systems. There is uncertainty in the estimation of skin cancer and bladder cancer risks associated with arsenic exposure. Although there is general consensus about the health risk posed by arsenic in drinking water at the very high levels that have been studied, there is no direct evidence to base risk estimation for levels of arsenic at or below current at or below current drinking water guidelines.

RECOMMENDATIONS

The responsibility for the safety of private well-drinking water lies with the property owner. For the purpose of protecting the health of the resident individuals, as well as the health of others, the following recommendations can be made:

(1) Well owners should actively monitor arsenic concentrations in their well water.

The IMAC of 25 µg/L for arsenic from the Canadian Drinking Water Guideline applies to public water systems. The groundwater found in wells may contain higher levels of arsenic. Therefore, private well owners are encouraged to take special precautions and actively monitor arsenic concentrations in their well water. The Regional Health Authorities, through their Environmental Health Officers, are able to provide further information on well water testing and on the laboratories certified for arsenic testing.

(2) One-time elevated arsenic levels, exceeding the recommended 25 µg/L Drinking Water Guideline require repeated sampling and monitoring.

If a domestic well is discovered to contain arsenic in excess of 25 µg/L, residents should repeat the sampling procedure to confirm the results within the next several weeks. If arsenic levels in the repeated samples are below 25 µg/L, residents are advised to follow-up with repeated sampling within next several months.

(3) If arsenic levels in a domestic well water consistently exceed 25 µg/L, an alternate source of potable water should be used for consumption and food preparation, or ways to reduce arsenic levels in the well water should be implemented.

Although, the IMAC of 25 µg/L for arsenic from the Canadian Drinking Water Guideline was established for public water systems, significant uncertainty remains in regards to the

potential health risks due to arsenic exposure from drinking water at or around these levels.

If repeated arsenic measures exceed 25 µg/L in subsequent samples for at least six times per year, residents should consider:

- a). limiting or discontinuing use of the well water for drinking or food preparation;*
- b). implementing means of reducing arsenic levels in the well to levels below the recommended guidelines.*

There are several ways to reduce exposure to arsenic found in the well water. Possible solutions include drilling a new well into another aquifer, connecting to a public water supply system, purchasing potable water, or installing water treatment devices.

The manufacture and sale of water treatment devices is not regulated in Canada. Residents should only use devices that have been certified to health-based standards. Water treatment technology information can be obtained from the Regional Health Authority offices. Water treatment devices require on-going maintenance to ensure that they are working properly. Periodic re-testing of the well is necessary.

(4) People with individual health concerns should visit their family physicians for advice.

Adverse health effects have been observed in some people who were exposed to very high levels of arsenic from drinking water. Arsenic levels in the domestic well water in the surveyed areas were significantly lower than in those where clinical manifestations could be expected. In any case, if residents have any individual health concerns, they should visit their family physician for advice.

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