Arsenic Levels in the Yellowknife Area: Distinguishing Between Natural and Anthropogenic Inputs

Prepared for

Yellowknife Arsenic Soil Remediation Committee (YASRC)

Prepared by

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February 2001
RMC-CCE-ES-01-01

EXECUTIVE SUMMARY

For over ten years, the Environmental Sciences Group (ESG) has been studying arsenic in the terrestrial and freshwater environment in Yellowknife, NWT. An intensive effort in the last four years has been focused on elucidating the background concentration range of arsenic in soils not impacted by mining operations.

Estimates of the background concentration of arsenic in the Yellowknife area were previously presented in three ESG studies and ranged from 5 to 100 ppm. The estimates were not based on samples from all geographical areas in Yellowknife and thus it was determined that additional samples should be collected to strengthen this conclusion.

In September of 2000 ESG collected additional soil samples to ensure coverage of all geographical locations in the Yellowknife area. Of particular interest were parks and playgrounds in the City of Yellowknife, Ndilo and Dettah. Samples were analyzed for a suite of elements by both neutron activation analysis (As, Sb, Au, Fe, Na, K) and inductively coupled plasma – optical emission spectrometry (Cu, Ni, Zn, Mn). All soil and surficial sediment samples in the ESG database of the Yellowknife area were subjected to statistical analysis.

In most residential areas arsenic concentrations are below 150 ppm. Three exceptions are the Rat Lake area, some locations in Ndilo, and on the Giant Mine Townsite. Elevated concentrations of arsenic in themselves are not necessarily cause for immediate concern.

After completing an extensive soil sampling program and rigorous statistical analysis (including principal components analysis, t-tests, and regression analysis), ESG is confident in reporting that the typical background concentration range of arsenic in the Yellowknife area is 3 to 150 ppm.

ESG is of the view that, particularly given the local prevalence of naturally occurring arsenic, there is not enough information at present to reach a decisive plan of action for the elevated levels of arsenic in soils in the Yellowknife area. Currently, we are developing risk assessment models that will incorporate arsenic speciation and measurements of its bioavailability.

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1 INTRODUCTION

For over ten years, the Environmental Sciences Group (ESG) has been studying arsenic in the terrestrial and freshwater environment in Yellowknife, NWT (Map 1-1). An intensive effort over the past four years has lead to the development of a statistical technique to determine the natural (background) concentration of arsenic in the Yellowknife area.

Several studies describing the levels of arsenic surrounding the Giant Mine,[1,2] the Con Mine,[3,4,5,6,7] and the City of Yellowknife[8] have been published by ESG in the last few years. All reported elevated levels in most of the soil, sediment, water, and plant samples collected.[9] Estimates of the background concentration of arsenic in the Yellowknife area, presented in three of the studies, ranged from 5 to 100 ppm[1,7,8]. As the estimates were based on limited information, it was determined that additional samples should be collected to strengthen this conclusion.

In September 2000, ESG carried out a study aimed at filling the data gaps pertaining to arsenic concentrations in soils. This work, included parks and playgrounds in Yellowknife, Ndilo and Dettah. In a concurrent soil study of arsenic contamination from the Giant Mine,[10] ESG obtained additional data on the Giant Mine Townsite and an area north of the mine.

The data set representing the Yellowknife area is now large enough that a picture of the background concentration of arsenic can be presented with confidence. This study uses all of the soil and surficial sediment data that ESG has collected over the past four years. Additional information on arsenic in the Yellowknife area has been collected and reported by others, but because of differences in analytical techniques it has not been included in this work.

The objectives of this report are:

- To discuss arsenic levels in various geographical areas in the vicinity of Yellowknife (more detailed discussion is provided for those areas not previously reported);
- to use statistical methods to elucidate the background concentration of arsenic in the Yellowknife area; and,
- to describe the approach that ESG is now using to evaluate the potential bioavailability, and the resulting risk, associated with arsenic levels in a variety of soil types from Yellowknife.

Map 1-1. Location of Yellowknife, NWT

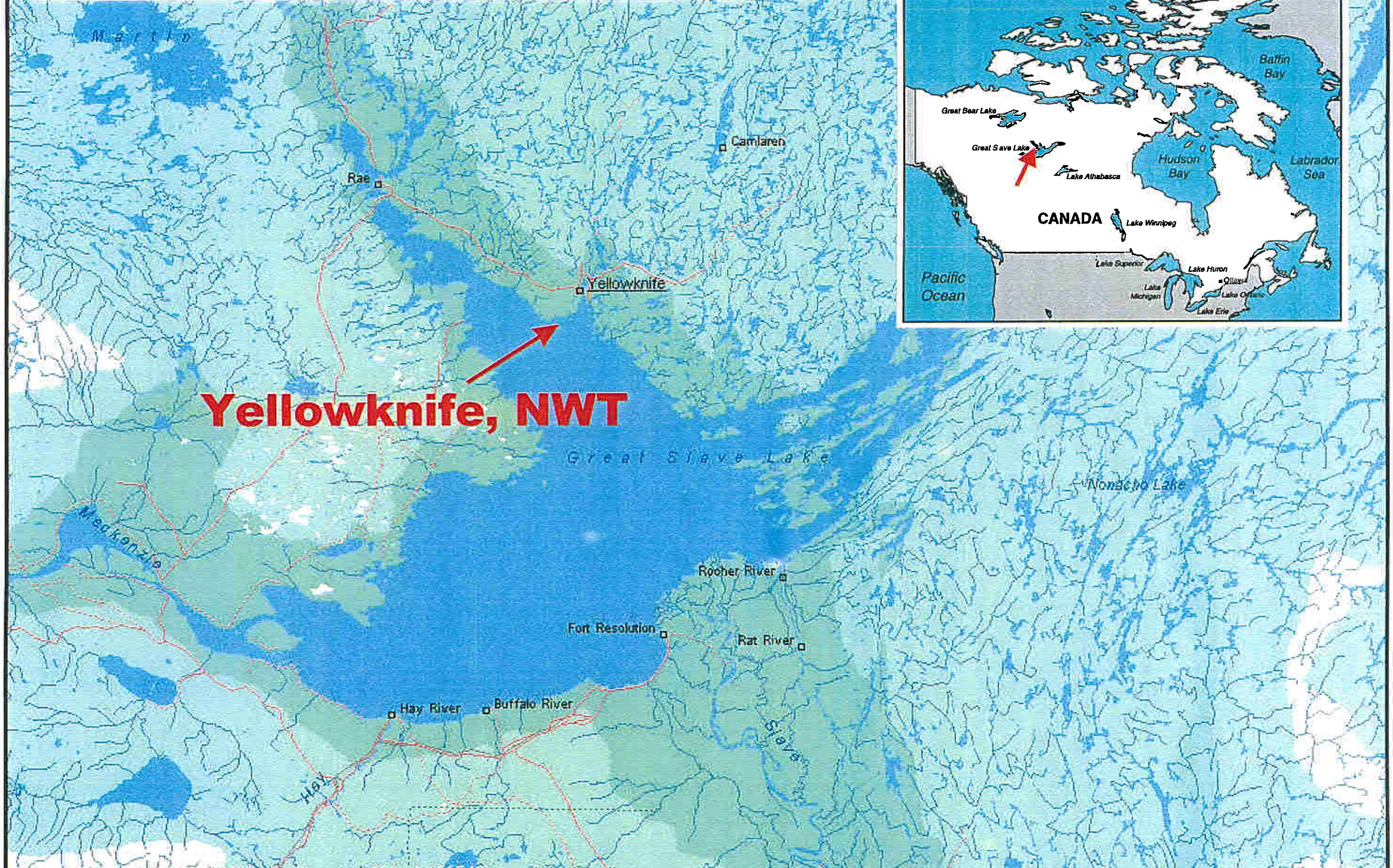

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Table 2-1: Some Environmentally important arsenic compounds

Name	Abbreviation	Chemical formula
	Inorganic Arsenic	
Arsenate, arsenic acid	As (V)	$AsO(OH)_3$, $[AsO(OH)_2O^-]$, $[AsO(OH)O_2 2^-]$, $[AsO_4^{3-}]$
Arsenite, arsenous acid	As (III)	$As(OH)_3$, $[As(OH)_2O^-]$, $[As(OH)O_2^{2-}]$, $[AsO_3^{3-}]$
	Organic Arsenic	
Monomethylarsonic acid,	MMA	$CH_3AsO(OH)_2$
Dimethylarsinic acid,	DMA	$(CH_3)_2AsO(OH)$
Trimethylarsine oxide	TMAO	$(CH_3)_3AsO$
Methylarsine	$MeAsH_2$	CH_3AsH_2
Dimethylarsine	Me_2AsH	$(CH_3)_2AsH$
Trimethylarsine	Me_3As	$(CH_3)_3As$
Arsenobetaine (fish arsenic)	AB	$[(CH_3)_3As^+CH_2COO^-]$

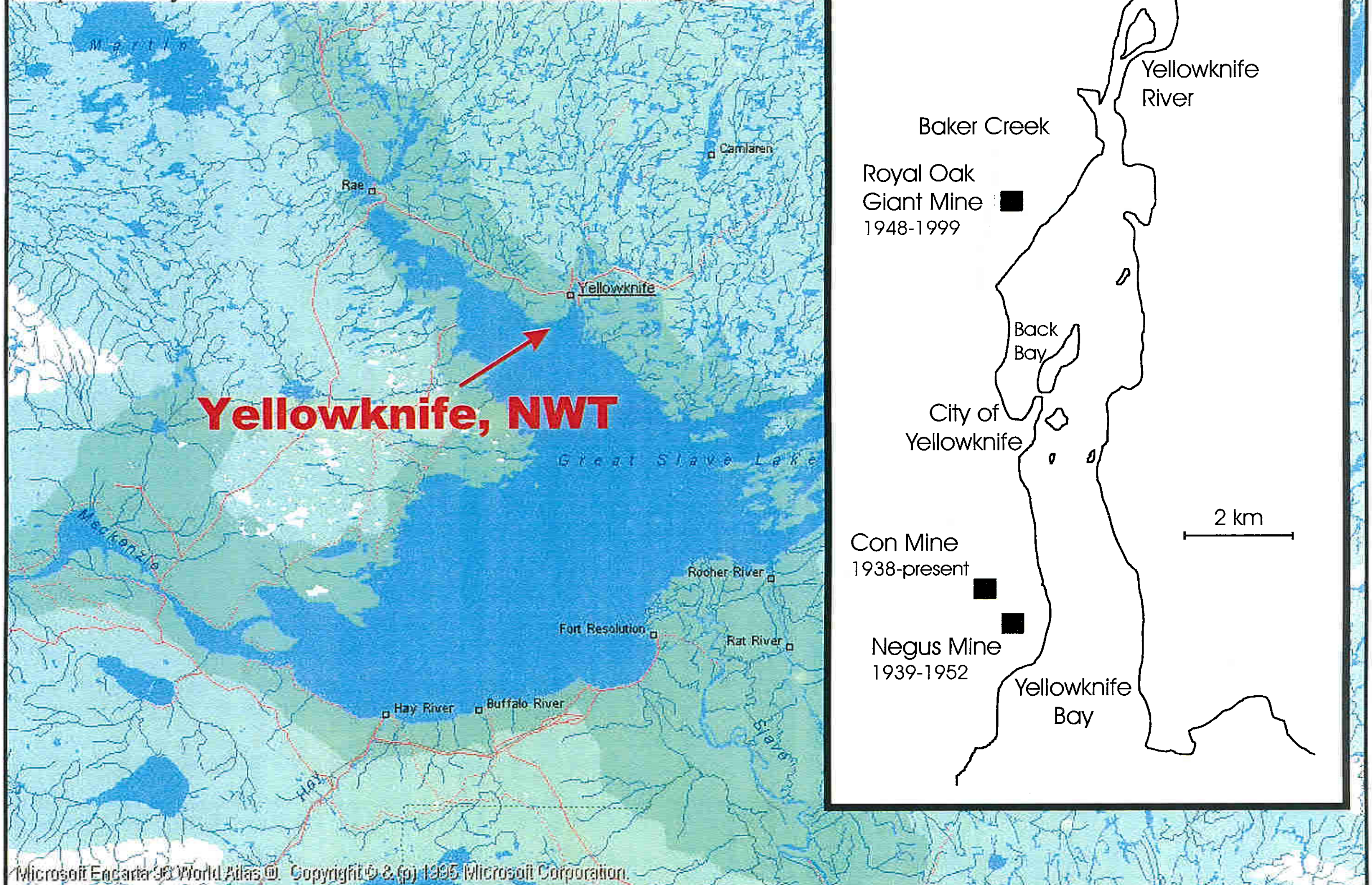
2.2 Arsenic in Yellowknife

The typical Canadian background concentration range of arsenic is between 5 and 14 ppm in soils. In areas associated with gold mining, however, natural arsenic levels have been reported to be much higher, with background concentrations of up to 250 ppm[14]. This is a result of natural weathering of local arsenic-rich minerals. In these areas, arsenic concentrations in soils, sediments and water tend to be much higher than the typical national average[14].

The city of Yellowknife, NWT has been an active gold mining community since 1938. Three mines have operated in the city over the last sixty years under various owners: Con Mine, Negus Mine and the Giant Mine (Map 2-1). Currently, the Miramar Mining Corporation owns all three properties, but carries out milling only at Con Mine. For several years it has been known that gold mining has increased the levels of arsenic in some areas of Yellowknife. Ore mined in Yellowknife is refractory, meaning that the gold is found with arsenopyrite (FeAsS - an arsenic-iron sulphide). The milling of this arsenic-rich ore generates a considerable amount of arsenic waste.

In Yellowknife, the mining of arsenic-rich ores extracts rock that contains high levels of mineralogical arsenic. At this point, arsenic begins to be introduced into the environment through several processes associated with human activities. Open pit and underground

Map 2-1. City of Yellowknife and the location of mining operations



3 SAMPLING AND ANALYSIS

3.1 Field Study

The fieldwork was carried out in Yellowknife during the summer between 1997 to 2000. A targeted approach to environmental sampling was used in all phases in the study. Special emphasis was placed on obtaining samples representative of the various geographical areas.

Soils Samples

Samples were obtained using a plastic scoop and stored in a Whirl Pak™ bag. The plastic scoops were discarded after each sample was obtained. Each sample was given a blind number, which was the only number provided on the label when submitting for analysis. Soil samples to be analyzed for inorganic elements were kept at a temperature of less than 0 °C, prior to and during shipping and long-term storage.

Sediment Cores

A modified Kajak-Brinkhurst (KB) gravity corer outfitted with a 120 × 9 cm polyacrylic tube was used for obtaining sediment cores. The cores were obtained by lowering the corer into the sediment from a boat. For depths of water less than 1 m, the tubes were forced into the sediment by hand. The cores were topped with overlying water to prevent contact of the sediments with air, and kept at 4 °C until processing. Cores were processed within 12 hours of collection. After processing, which involved dividing the core into 5-cm sections and collecting the porewater, the squeezed sediments were stored in Whirl Pak™ bags and frozen. Each sample was given a blind number, which was the only number provided on the label when submitting for analysis.

Sampling locations and descriptions were recorded in field notebooks and/or on field maps, and a photographic record was made of each general area that was sampled. Sampling locations for this study were not surveyed and all locations indicated on maps are considered to be approximate within a few metres.

Chain-of-custody forms for each sample were filled out and checked before shipment, and the contents of the shipments were verified upon receipt in the laboratory. The relevant documentation is available on request.

3.2 Analysis

Analyses were conducted by two laboratories accredited by the Canadian Association of Environmental Analytical Laboratories (CAEAL): the Analytical Services Unit (ASU), cooled for 80-120 hours, and then counted for 2 hours using a GMC HpGe detector coupled with a Nuclear Data μ-multichannel analyzer (MCA).

3.3 Statistical Analysis

3.3.1 Principal Components Analysis

The solid-phase compositions of samples (using the suite of ten elements: arsenic, antimony, iron, gold, nickel, copper, zinc, manganese, potassium, and sodium), were compared using the multivariate statistical technique, principal components analysis (PCA). The analysis was carried out with the statistical program SYSTAT® 8.0. This technique allows for multivariate pattern recognition of the metal concentrations for each sample by examining their position on a reduced (usually two- or three-dimensional) plot. The axes of the plot are linear combinations of the original *n* variables.

The data for each metal concentration and sample set were normalized (typically using log, log10, square root) to eliminate the effect of a large range of metal concentrations over the data set.

The selection of the suite of ten elements used was based in part on previous studies in the area. Arsenic, antimony and gold are components of the mined ore. Iron and zinc are additives in the milling and effluent treatment process, and the others are environmentally important elements. Due to financial constraints on this work, three of the elements included in Mace's 1998 analysis[1] were not used (cobalt, calcium, and lanthanum).

3.3.2 Paired t test

The paired t test can be used to compare measured means with separately determined means. In this case the means from the three different groups identified within the PCAs were examined. First the pooled standard deviation (s_p) was calculated using the standard deviations from each group and the t value was calculated. The calculated t value was then compared with the value for t from the Student's t table using N_2-2 degrees of freedom. If this value is greater than t from the table, then there is a statistical difference between x_1 and x_2 (that is, x_1 and x_2 are not from the same population).

3.3.3 Linear Regression and Correlation

Linear regression is the procedure for describing the best-fitting straight line that summarizes a linear relationship between two variables. It is expressed by the equation $y=mx+b$. To use this technique, two basic assumptions are made. The first is that y values are equally spread out around the regression line throughout the values of x, and the second is that at each value of x, the y values are normally distributed. A correlation

4 RESULTS AND DISCUSSION

The first part of this chapter describes the concentrations of total arsenic in the Yellowknife area. The second part gives an interpretation of the data using statistical relationships. Complete data tables can be found in Appendix A, and quality assurance/ quality control (QA/QC) results are presented in Appendix B.

4.1 Total Arsenic Concentrations in Soil and Surficial Sediment Samples

4.1.1 Giant Mine and Surrounding Property

Elevated arsenic concentrations were seen in almost all samples collected on the Giant Mine property from the tailings ponds, Mill site, Townsite and Baker Creek.

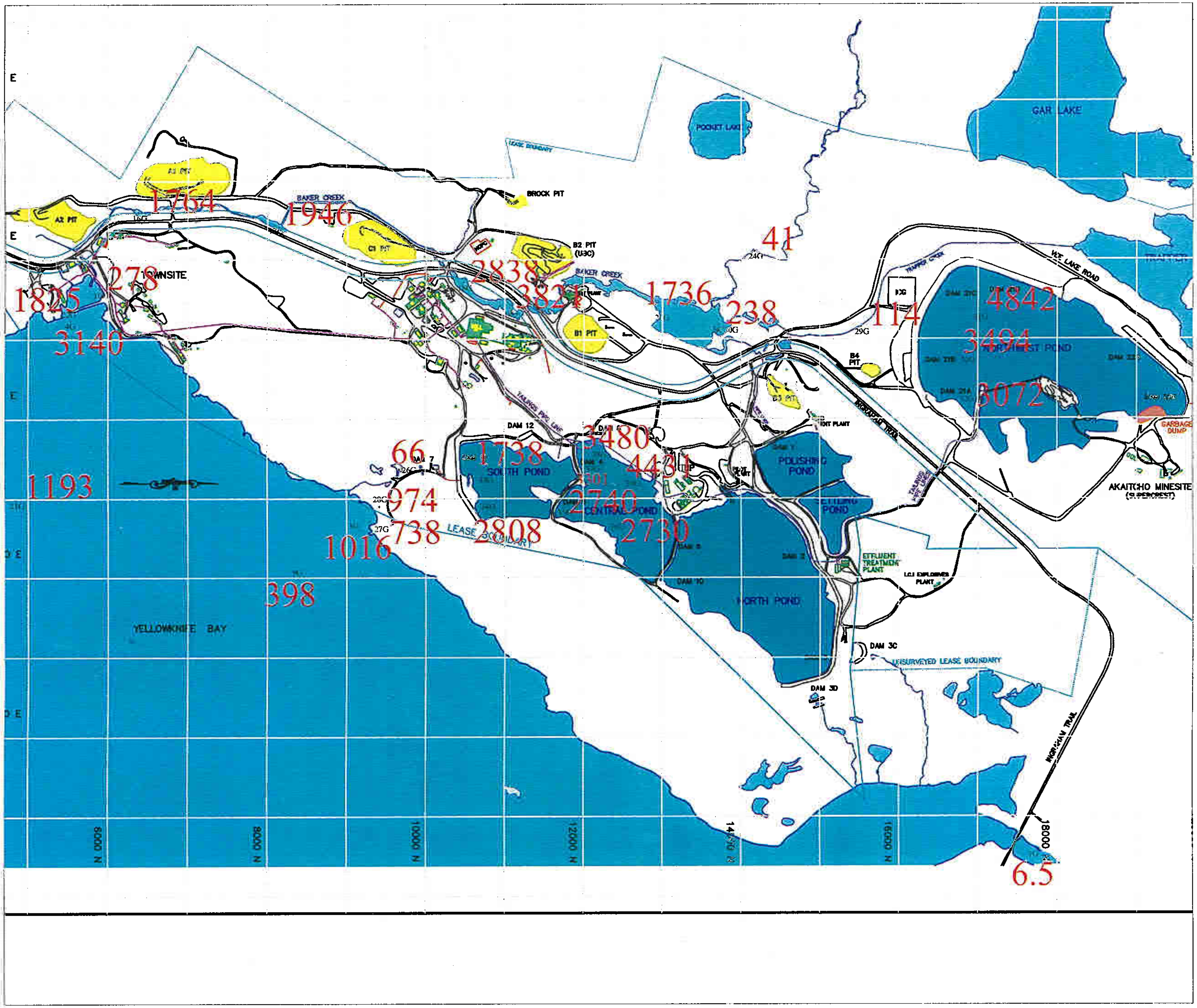
In 1997, samples were collected from the Tailings Ponds, Beach Tailings area, Baker Creek, and Back Bay (Map 4-1).[1] The average arsenic concentration in the tailings ponds was 3264 ± 950 ppm, reflecting the input of the solid and liquid waste streams from the mill process. In samples collected from the Beach Tailings area south of the South Tailings pond the average arsenic concentration in soil and sediment was 909 ± 150 ppm.. Historically, tailings were deposited along the shore of Back Bay in this area. At 300 m offshore, the arsenic concentration remained high (398 ppm at sample location 9G). The average concentration in surficial sediment (0-5 cm) from Baker Creek and its outflow was 2024 ± 1101 ppm,. Arsenic-contaminated sediments were found outside the Baker Creek outflow breakwater (3140 ppm at location 4G) and up to 1 km away concentrations remained high (1193 ppm).

In September 2000, ESG was given permission to sample around the Giant Mine Mill Site (Map 4-2). As expected, the highest level of arsenic was found at the base of the roaster stack (87,000 ppm at location 29206). Concentrations of this magnitude can be attributed to the fallout of arsenic trioxide during the roasting of arsenic-bearing ores. A sample taken in an area where roaster calcines were previously stockpiled (location 29211) contained 21,500 ppm arsenic. The concentration in a sample representative of the ore currently being mined at the mine (location 29213) was 5462 ppm.

Samples collected from the Giant Mine Townsite in September 2000 (for a separate INAC study on arsenic levels at the Giant Mine Townsite and an area north of the mine) had arsenic concentrations of between 19 and 1850 ppm (Map 4-3). The highest concentrations were found associated with crushed rock fill on the roadways; these had an average concentration of 1174±519 ppm. The average concentration in samples whose matrices were not rock was 87±95 ppm (range: 19 - 366 ppm). This suggests that arsenic

Photo 4-1. The Giant Mine

Photo 4-2. Baker Creek



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Grid Scale: 1000 ft

PUT INSET MAP HERE

LEGEND:

29000 Sample Tag Location

234 Arsenic Concentration [ppr

NOTES:

Map 4-1. Giant Mine property with arsenic concentrations (p from tailings ponds, Baker Cre and Back Bay shown in red.

ORIGINAL SOURCE:
Miramar Giant Mine Ltd.

UPDATED: Dec 4/2000
Chris Ollson
PRINTED: DEC 4/2000

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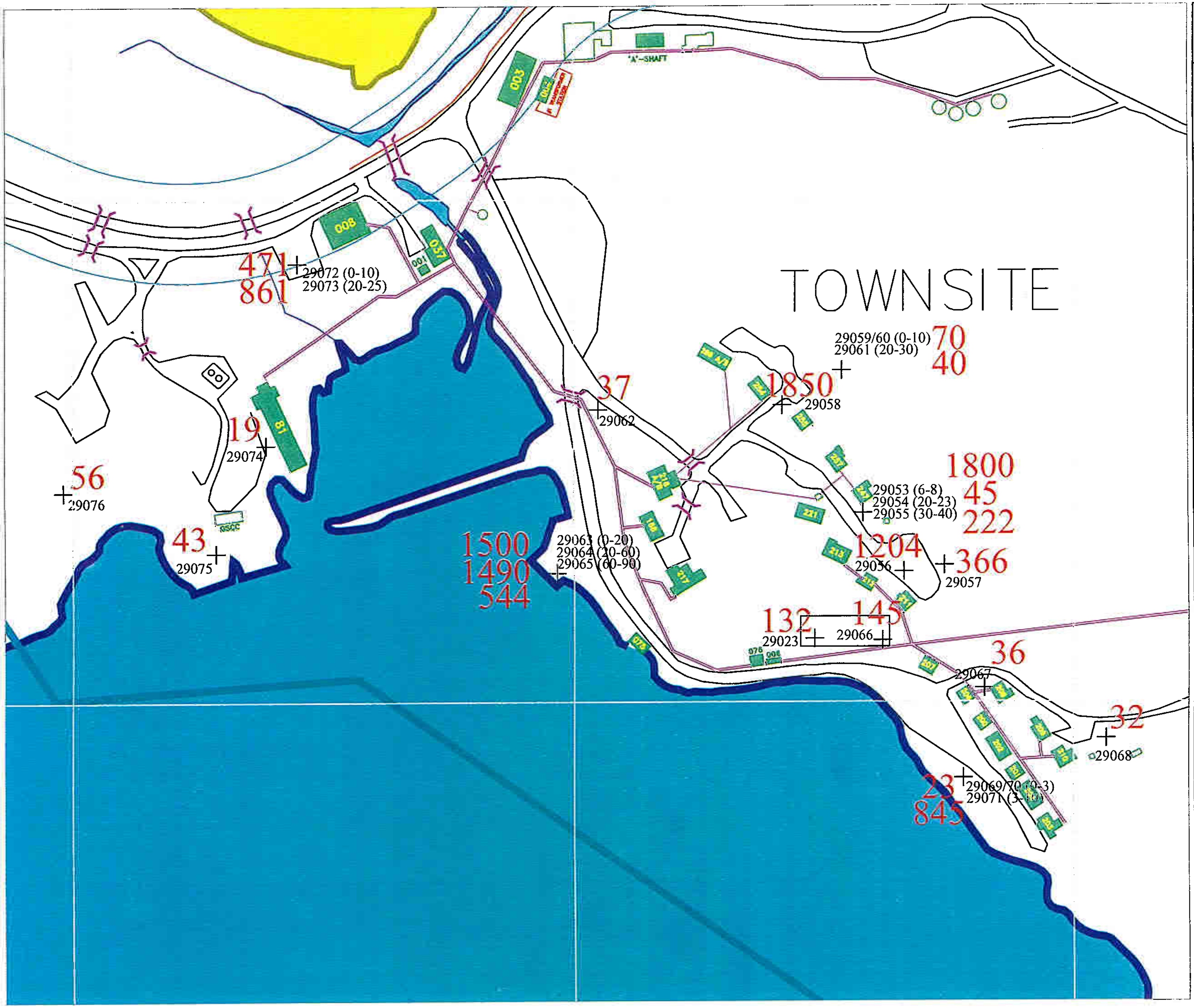

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Grid Scale: 1000ft

LEGEND:

29000 Sample Tag Location

234 Arsenic Concentration [ppm]

NOTES:
Depth of samples is indicated in brackets (cm)

MAP 4-3. Arsenic concentration (ppm) from the Giant Mine Townsite are shown in red.

ORIGINAL SOURCE:
Miramar Giant Mine Ltd.

UPDATED: NOV.22/2000
Chris Ollson
PRINTED: NOV.22/2000

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4.1.2 Con Mine and Surrounding Property

As found at the Giant Mine, arsenic concentrations were elevated in all samples collected on the Con Mine property from the tailings ponds, areas surrounding tailings ponds, Mill Site, Rat Lake, Frame Lake and the Meg-Keg-Peg Lake Great Slave Lake watershed. The Con Mine, too, has been operating for over sixty years and has seen its environmental practices change several times.

In a recent study, arsenic (Map 4-5) and cyanide levels (not shown) on the Con Mine property and surrounding area were examined[7]. The average arsenic concentration in the Con Mine and Negus Tailings Ponds was 6311±7095 (range: 1400- 25,000 ppm, median: 3017 ppm). Concentrations in the Con ponds were higher than in the Giant Mine tailings ponds. The median concentration in soils from the perimeter of the ponds was 118 ppm (range: 5-1165 ppm), and concentrations appeared to decrease with distance from the ponds.

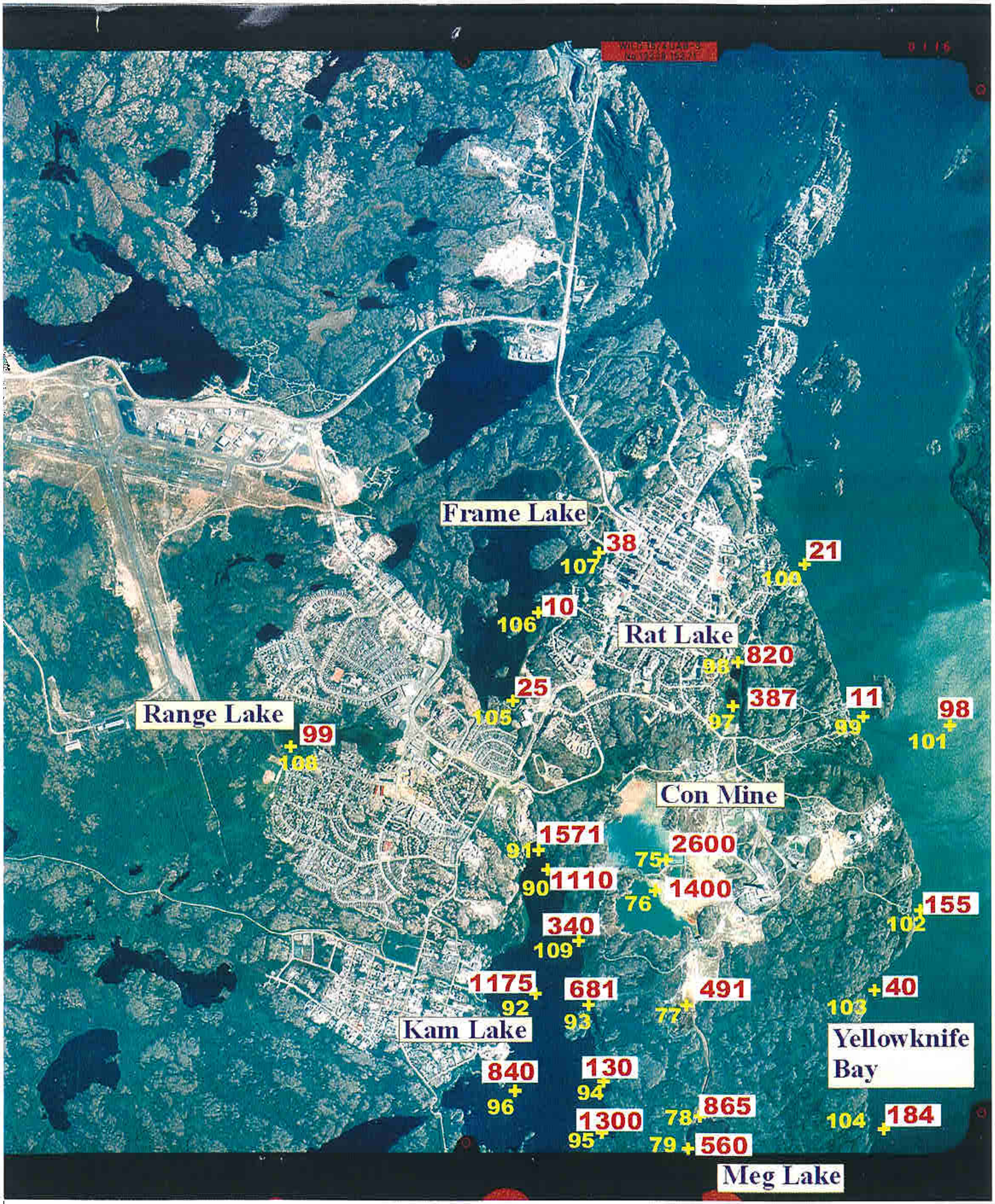
Concentrations of arsenic found in an area surrounding Rat Lake and along the Con Mine fence line near the secondary access gate resembled those found in tailings (Map 4-5). The average concentration of arsenic in samples from this area was 812±204 ppm.

Sediment samples were collected in lakes surrounding the Con Mine Property and from Yellowknife Bay (Map 4-6 and 4-7). The arsenic concentrations in the surficial sediments (0-5 cm) of all cores collected exceeded the federal interim sediment quality guidelines. Kam Lake sediment cores had an average arsenic concentration of 893±491 ppm, clearly demonstrating the historical impact of the Con Mine operations. Rat Lake sediment also had elevated concentrations (387 ppm and 820 ppm), which can also be attributed to historical practices of mill operations.

The Meg-Keg-Peg Lake-Great Slave Lake watershed was also revisited. In samples collected down the watershed system, arsenic concentrations increased from 865 ppm in Meg Lake to 5550 ppm in Peg Lake. Beyond the arsenic peak at Peg Lake, the concentration dropped dramatically towards the Great Slave Lake outflow. The concentrations in the top of the cores from the system were within the same order of magnitude as those found earlier by ESG[3].

Photo 4-7. Negus Tailings Pond located east of Con Mine.

Photo 4-8. Rat Lake from the north looking towards Con Mine.



Map 4-6. Sediment core sample locations in and around the city of Yellowknife. Arsenic concentrations (ppm) from surficial sediments (0-5 cm) are indicated in red.

4.1.3 Yellowknife Residential Areas

4.1.3.1 City of Yellowknife

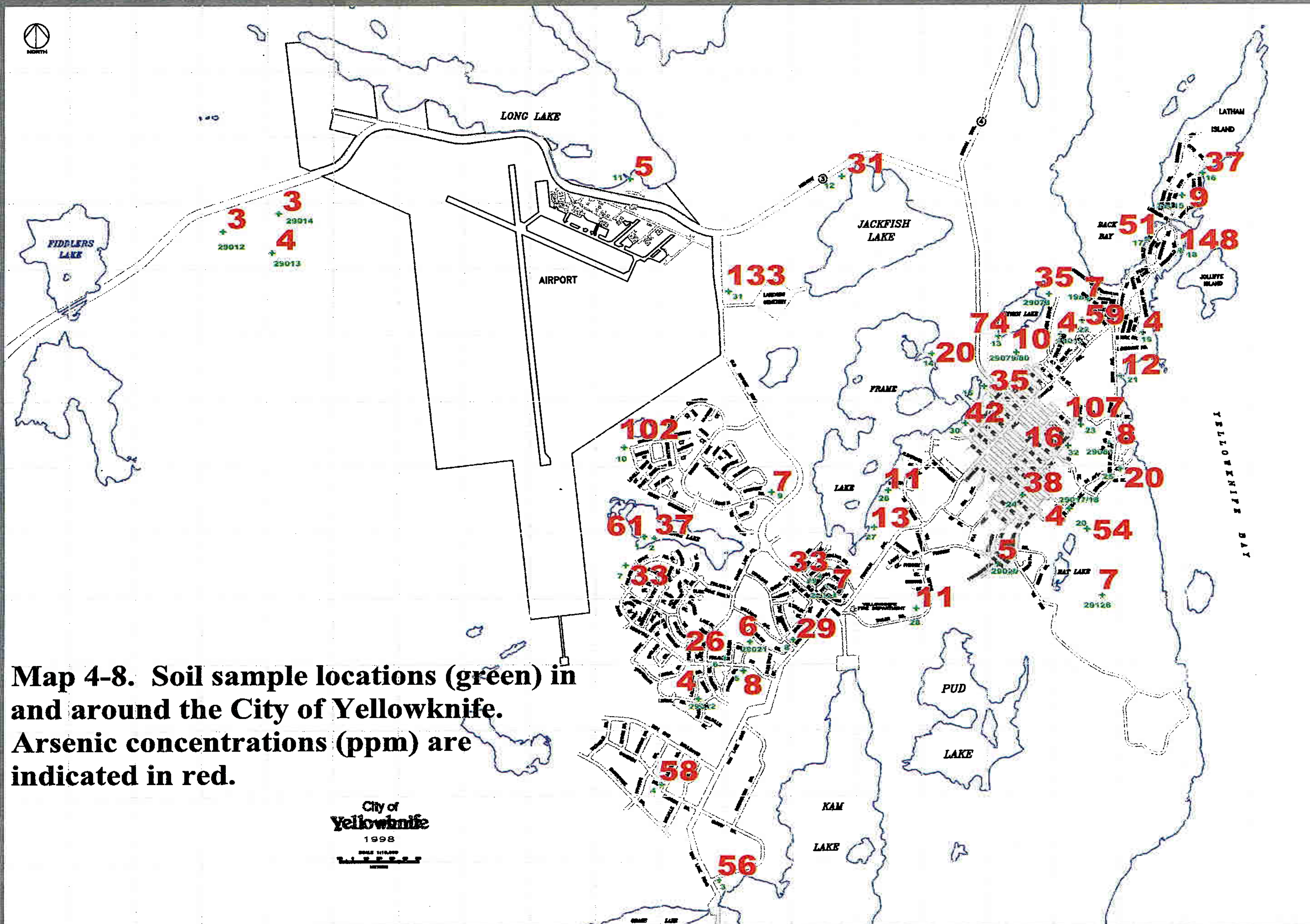
Forty-seven soil samples from around the City of Yellowknife were collected between 1998 and 2000 (Map 4-8). Sampling was focused to ensure that all neighborhoods and playgrounds received representative coverage. The average concentration of arsenic in the city was 32±34 ppm (range: 3-148 ppm). The samples collected from playgrounds and parks exhibited the lowest concentrations (3-13 ppm).

4.1.3.2 Ndilo

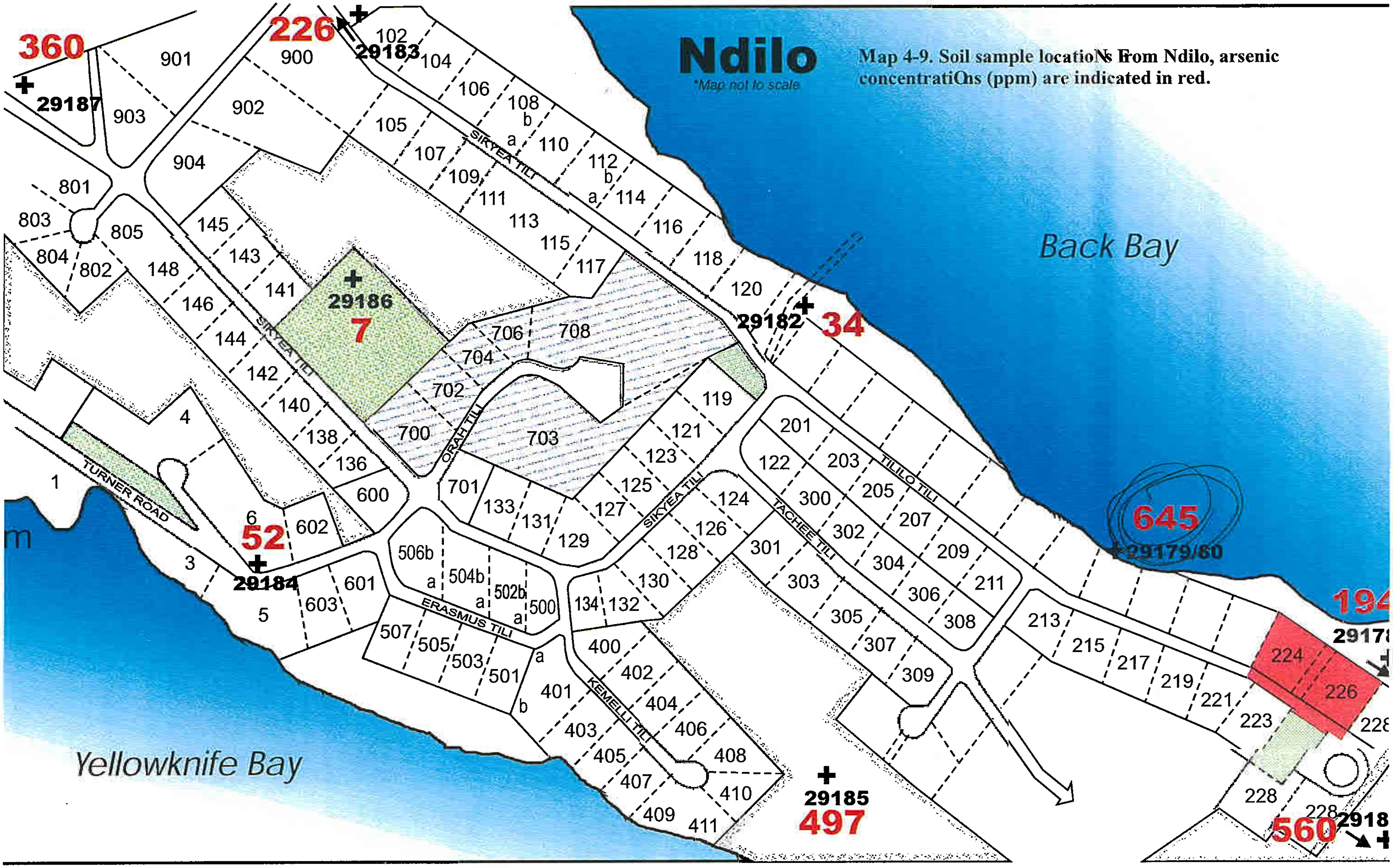
Ndilo is located on the northern tip of Latham Island and is home to members of the Yellowknives Dene First Nation. Samples were collected in Ndilo, with permission from Chief Peter Liske, in September 2000. Sampling was carried out in areas frequented by people, along the shoreline, and on top of a hill (Map 4-9). The average concentration of arsenic was 286±240 ppm (range: 7-645 ppm). The source of the elevated levels of arsenic is unknown at this point; two possibilities include that the elevated levels may be indicative of a unique geology and/or a reminant of historical aerial emissions from the Giant Mine roaster stack. Importantly, the arsenic concentrations found in the playground and other easily accessible areas were all within the range of background concentrations. It should also be noted that there are several other residential areas in Yellowknife that have comparable levels (for example, Rat Lake and the Giant Mine Townsite). For these reasons, therefore, the presence of elevated concentrations of arsenic in Ndilo is not necessarily a cause for immediate concern.

4.1.3.3 Dettah

Dettah, also a home of Yellowknives Dene First Nation people, is located across Yellowknife Bay from Yellowknife. Seven soil samples were collected in Dettah, with permission from Chief Richard Edjericon, during September 2000. The samples were taken in areas frequented by people, and were selected to be representative of the area (Map 4-10). The average arsenic concentration was 50±56 ppm (range: 7.2-144 ppm). All samples collected in Dettah are believed to be representative of the natural or background level of arsenic in the area.



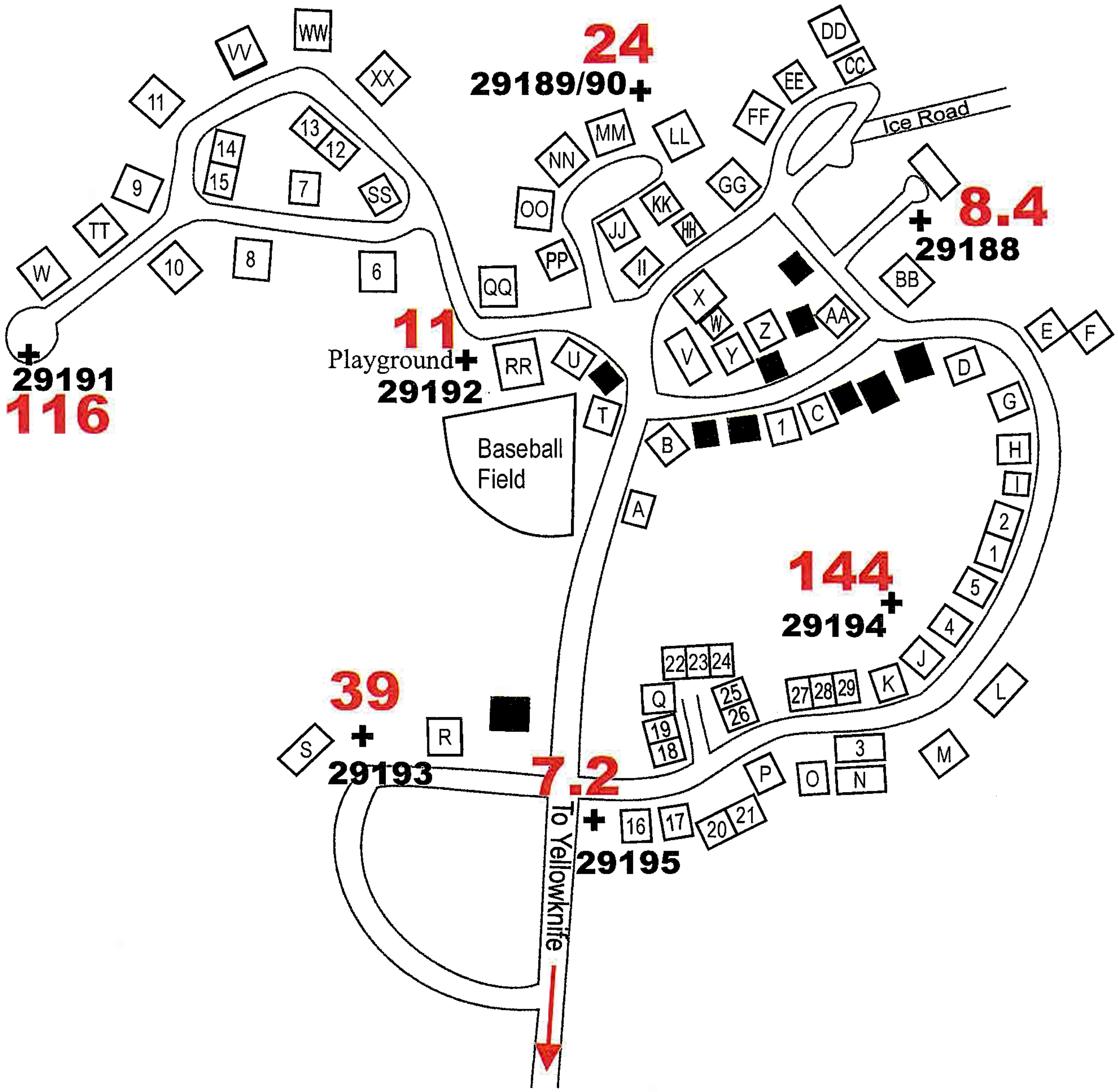
Map 4-8. Soil sample locations (green) in and around the City of Yellowknife. Arsenic concentrations (ppm) are indicated in red.



Map 4-9. Soil sample locatioNs Ifom Ndilo, arsenic concentratiOns (ppm) are indicated in red.

Dettah

**Map not to scale*



Map 4-10. Soil sample locations from Dettah, arsenic concentrations (ppm) are indicated in red.

average concentration of 5±0.3 ppm. These samples were collected in sand from playgrounds and other high use areas.

- A loose grouping of samples below the -1 value of the y-axis is evident. These include samples collected from around the perimeter of the Con Mine Tailings Ponds, some Ndilo samples, and one sample from Dettah. The range of arsenic in these samples is 34-676 ppm. It is possible that this grouping reflects a higher background concentration in these areas, or it may represent soil that was impacted by the roaster stack, mine waste dust, or other fugitive emissions.

- When all of the samples are included in the same PCA, there is overlap between the groupings. This is illustrated by the overlap of the ellipses on the plot. Of interest is the placement of the Ndilo samples. Several of the samples fall on the y-axis between all three groupings. Possibly these samples were influenced by aerial emissions from the Giant Mine.

- When the groupings are compared statistically, using a paired t-test and pooled standard deviations, there is a significant difference between all three groupings: background (green ellipse) and anthropogenic (red ellipse) (t=9.14, df=183, p<0.01), background and loose grouping (t=8.67, df=125, p<0.01), and anthropogenic and loose grouping (t=4.12, df=108, p<0.01).

Based on the large number of samples (219) and the results of the PCA and paired t-tests, the background concentration of arsenic in the Yellowknife area covers a range of 3-150 ppm. Although the range in the "background" ellipse is 3-300 ppm, 99.5% of the samples have a concentration of less than 150 ppm. This also indicates that in some isolated cases the natural concentration of arsenic may be as high as 300 ppm.

4.2.2 Principal Components Analysis of ESG Yellowknife Soil and Tailings Samples

The mandate of the Yellowknife Arsenic Soil Remediation Committee is to deal exclusively with soil (and not sediment). Therefore, the solid-phase compositions of only soil and tailings samples from the Yellowknife area also underwent principal components analysis, using the suite of ten elements (arsenic, antimony, iron, gold, nickel, copper, zinc, manganese, potassium and sodium).

The positions of tailings and soil samples from the City of Yellowknife, Ndilo, Dettah, Con Mine property and Giant Mine property are illustrated in Figure 4-1. The elemental distribution is shown in the top plot (factors plot). The first two principal components combine to explain 72% of the between-sample variance in the original data set (52% and 20% for principal components 1 and 2).

As before, two distinctive groupings of sample locations occur. Most of the important features of Figure 4-2 are similar to those in Figure 4-1. Additional features of Figure 4-2 are as follows:

- The arsenic concentration range of samples within the red ellipse is 29-12,600 ppm. The average concentration is 1967±2042 ppm, with a median value of 1580. Again, this ellipse contains all samples that were directly impacted by mine waste.
- The arsenic concentration range in the green ellipse is 2.5-218 ppm. The average concentration is 42.2±51.7 ppm with a median value of 26 ppm. This ellipse contains samples that reflect the background concentration range of arsenic in the Yellowknife area.
- A loose grouping of samples below –2 value of the y-axis is evident. These were collected from around the perimeter of the Con Mine Tailings Ponds, and include one sample from Dettah. The range of arsenic in these samples is 34-506 ppm. The average concentration is 206±165 ppm, with a median value of 157 ppm. This result may reflect a higher natural concentration of arsenic on the mine property, distinct from that found off site.
- A statistical comparison of the groupings using a paired t-test and pooled standard deviations determined that there is a significant difference between all three groupings: background (green ellipse) and anthropogenic (red ellipse) (t=9.0, df=156, p<0.01), background and loose grouping (t=8.25, df=112, p<0.01), and anthropogenic and loose grouping (t=4.04, df=88, p<0.01).

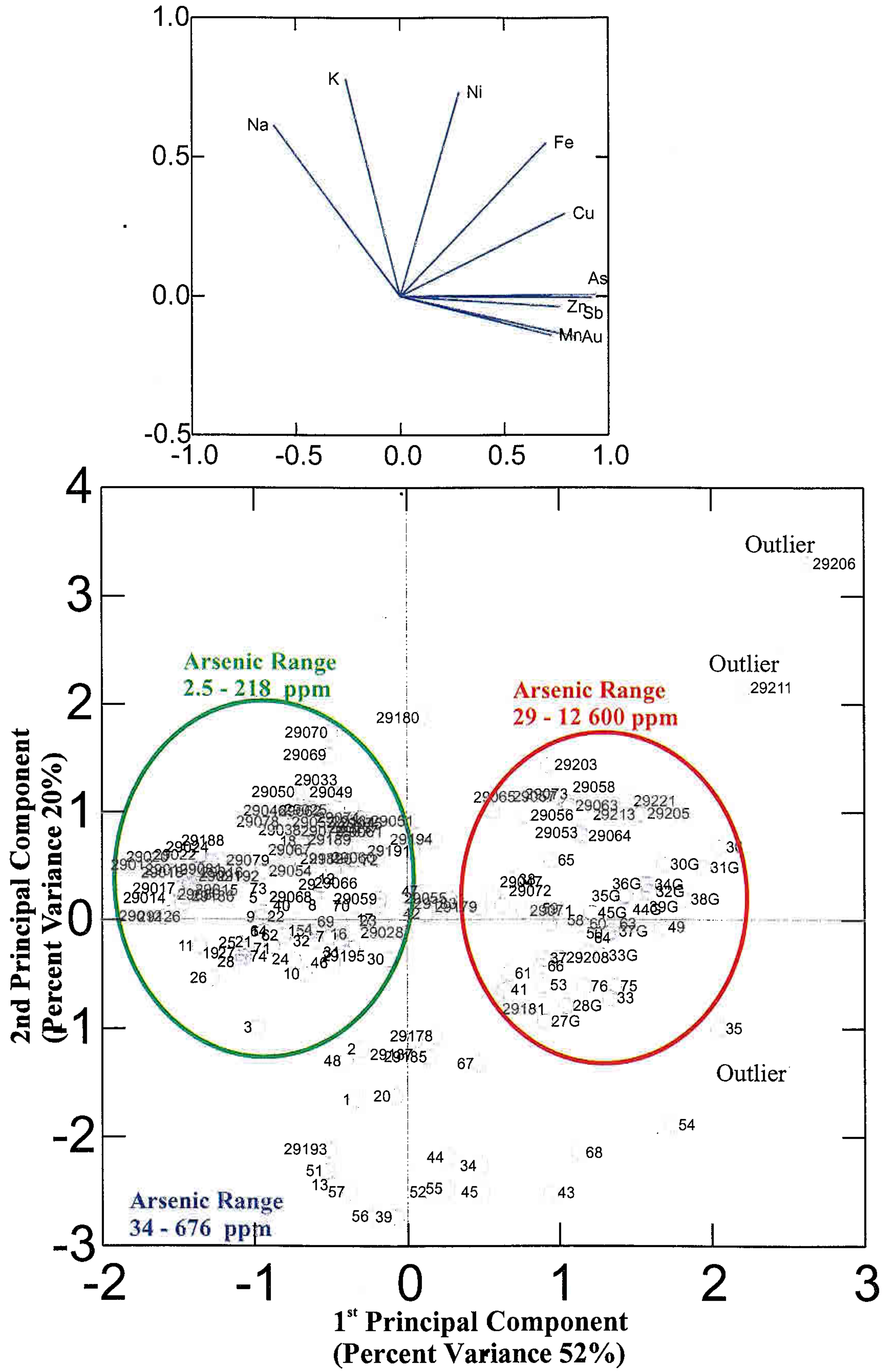


Figure 4-2. Principal components analysis biplot of soil and tailings samples from the Yellowknife area. The green ellipse on the left side of the plot is indicative of the natural concentration range of arsenic in the Yellowknife area. The red ellipse on the right contains samples impacted by mining operations.

6 NEXT STEPS

This chapter describes ESG's current research on characterizing the bioavailability and chemical forms of arsenic found in the samples collected in the area of Yellowknife.

With total concentrations of arsenic known, the question becomes: do these levels pose a risk to the environment or human health? Using traditional risk assessment models based on total arsenic levels, and the CCME recommended soil quality guideline of 12 ppm as a benchmark, the answer would be yes. Clearly this is an unrealistic outcome, as it would involve cleaning up the natural geology of the area.

The CCME recommends that the natural or background concentration be taken into consideration when assessing risk. In the Yellowknife area, this range has been established as 3-150 ppm. Another important consideration concerns the form, or speciation, of arsenic. It is now widely accepted in the scientific community that knowledge of arsenic forms is crucial to any assessment of the risk from arsenic to either the ecosystem or human health. This criterion, rather than one based solely on total arsenic, should be used in assessing risk.

An approach that is at least tangible is to deal with mine waste that exists in obviously unconfined areas. Less clear is how to treat concentrations that are above background but are not obviously mine waste. It is these soils that need a more detailed assessment, to avoid under or overestimating the risk. ESG is of the view that, particularly given the local prevalence of naturally-occurring arsenic, there is not enough information at present to reach a decisive plan of action for this material.

Currently, we are developing risk assessment models that will incorporate arsenic speciation.

6.1 Current Research of Arsenic at the Environmental Sciences Group

A preliminary analysis of arsenic species in waters and biota of the Yellowknife area is being used to explore the link (if any) between high levels of arsenic and the risk of arsenic to human and ecological health. Many questions remain, such as: Given that toxic species are the major ones extracted from many biota (higher plants, moss, algae, lichens and some fungi), how bioavailable are they? What form of arsenic is in humans' food (such as mushrooms, locally grown vegetables, local game)? And how bioavailable is it?

The measure of arsenic bioavailability usually involves administering a dose to a laboratory animal and measuring the levels of arsenic in blood or urine compared to the dose given (Absolute bioavailability = (Total amount of arsenic in blood/urine from

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8 APPENDICES

8.1 Appendix A: Data

The following section contains data tables and soil sample locations and descriptions.

Table 8-1. Elemental concentrations [ppm] for sample locations reported.

Sample Location	As [ppm]	Sb [ppm]	Fe [ppm]	Au [ppm]	K [ppm]	Na [ppm]	Zn [ppm]	Mn [ppm]	Cu [ppm]	Ni [ppm]
25	20	0.4	12000	0.005	18000	24500	100	18	5.7	8.6
26	11	0.2	12000	0.005	14000	23100	11	93	3.7	7.8
27	13	0.3	11000	0.005	17000	24000	131	21	6.1	7.9
28	11	0.2	12000	0.005	14000	23100	16	128	9.8	10
29	33	0.4	19000	0.005	17000	25000	56	185	48	35
30	42	1.5	16000	0.1	13000	14400	94	380	34	29
31	133	5.5	15000	0.04	15000	23000	26	192	13	12
32	16	0.5	15000	0.03	15000	18300	199	34	20	19
33	7500	65	49000	3.18	4000	6600	946	182	56	50
34	121	12	7000	0.5	1000	500	112	176	76	11
35	25000	94	1500	1.99	7000	500	553	4622	11625	93
36	12600	58	72000	2.33	11000	14300	849	3094	6031	74
37	1165	10	36000	0.06	8000	9100	2946	190	119	37
38	69	1.8	85000	0.03	7000	5200	120	65	2028	65
39	57	8.8	1000	0.03	1500	500	64	155	32	2.5
40	29	0.5	22000	0.01	19000	24100	32	185	13	19
41	2472	40	52600	0.84	7000	8600	56	173	15	22
42	300	9.4	25000	0.2	18000	20400	59	304	41	18
43	506	13	8000	4300	1500	1700	632	57	17	6.7
44	372	27	4000	0.14	1500	600	62	47	40	12
45	294	22	4000	0.2	1500	1000	244	444	26	5.4
46	174	0.8	19000	0.005	11000	12200	12	74	48	16
47	114	1.8	34000	0.2	16000	19200	51	362	92	32
48	82	1.3	8000	0.02	6000	4100	11	90	36	15
49	5028	645	58000	1.07	12000	4300	477	1023	261	58
50	3433	54	57000	1.3	16000	2600	210	1389	98	51
51	47	3.5	1800	0.09	2150	1700	5.0	16	55	2.5
52	34	9.3	1200	0.22	1500	500	80	224	56	6.7
53	2461	34	43000	0.37	9000	3100	20	1078	99	32
54	443	40	5000	8400	1500	500	1254	150	1066	45
55	379	9.9	6000	0.34	1500	500	154	71	13	6.3
56	193	7.1	1500	0.06	1500	500	43	26	14	2.5
57	90	2.3	8000	0.03	900	2000	5.0	186	16	2.5
58	1580	16	61000	0.32	10000	8200	1072	178	75	61
59	591	24	53000	1.16	7000	14300	868	135	97	68
60	566	8.7	77000	0.96	6000	11600	759	1114	102	79
61	41	7400	23000	0.03	5500	17000	39	911	193	24
62	21	0.8	15000	0.06	17000	25000	113	12	12	9.1
63	1860	64	69000	0.34	13000	3700	593	1203	110	58
64	994	104	40000	3	9000	4600	152	159	443	47
65	850	40	48800	1	19000	15000	282	608	135	67
66	717	27	42000	0.21	11000	4400	1183	117	74	29
67	676	31	14000	0.42	5000	4500	243	48	34	16
68	235	78	4000	25600	1500	2400	59	92	163	16
69	218	1.8	18000	0.02	17000	24000	210	29	12	16
70	74	2	21000	0.03	18000	21900	240	39	23	20
71	30	0.16	14700	0.005	15000	24000	16	135	7.2	12
72	29	0.8	34000	0.005	25000	15500	473	64	26	35
73	12	0.3	20000	0.005	18000	24300	211	18	15	17
74	10	0.3	11500	0.007	16000	24000	16	119	12.5	7.4
75	2600	26	58000	3.78	6500	4020	415	986	82	47
76	1400	17	51000	0.37	6000	3830	292	962	166	39
77	491	11	29000	3.46	21000	14080	252	45	105	232
78	865	18	13000	16.8	5000	4940	1031	122	96	398
79	560	19	12000	27.6	4000	7010	1501	506	94	202
80	440	6.6	32000	5.87	22000	13630	380	100	101	293
81	1660	27	31000	20.9	19000	11710	156	80	74	276

Table 8-1. Elemental concentrations [ppm] for sample locations reported.

Sample Location	As [ppm]	Sb [ppm]	Fe [ppm]	Au [ppm]	K [ppm]	Na [ppm]	Zn [ppm]	Mn [ppm]	Cu [ppm]	Ni [ppm]
29059	71	6	18000	0.04	10000	12200	50	20	45	310
29060	68	5.8	23000	0.03	15000	12600	49	21	46	354
29061	40	1.2	36000	0.003	16000	14000	59	34	69	457
29062	37	0.7	18000	0.065	15000	30800	39	17	77	228
29063	1500	61	77000	0.89	11000	10400	105	77	178	1100
29064	1490	43	79000	1.2	9000	5700	100	97	156	1266
29065	544	27	45000	0.28	13000	16200	86	64	99	934
29066	145	5.8	17000	0.2	15000	23400	9.4	12	26	135
29067	36	1.6	17000	0.011	15000	20600	12	13	26	159
29068	32	3.8	11000	0.034	13000	13900	14	9.5	38	186
29069	25	2.5	17000	0.02	25000	27700	37	10	174	503
29070	20	2	16000	0.014	28000	27100	23	10	597	458
29071	845	12	35000	0.4	5000	4800	91	62	149	986
29072	471	18	32000	0.18	6000	5400	75	64	119	927
29073	861	44	77000	0.74	9000	13600	85	68	129	1185
29074	19	2.4	32000	0.008	16000	15900	28	29	42	325
29075	43	2.5	23000	0.011	18000	22400	31	32	44	263
29076	56	4.4	24000	0.02	16000	21600	27	26	41	298
29077	64	6.1	28000	0.008	19000	21300	15	20	34	229
29078	35	0.9	22000	0.005	18000	27200	19	19	27	190
29079	11.6	0.3	12000	0.002	17000	24900	12	11	21	103
29080	8	0.2	10000	0.005	12000	23800	11	13	22	104
29081	7.6	0.21	12000	0.001	18000	24500	9.1	10	20	99
29126	7	0.2	8000	0.01	16000	23200	6.4	6.6	7	66
29178	194	29	8000	0.09	3000	2500	54	25	40	177
29179	510	24	22000	0.92	10000	9300	87	29	92	294
29180	780	23	23000	0.92	44000	29000	65	24	67	327
29181	560	21	17000	1.59	3000	7300	194	22	85	160
29182	34	1.1	20000	0.6	17000	23200	25	24	50	201
29183	226	56	15000	0.26	5500	9200	28	15	185	953
29184	52	3	21000	0.02	21000	21800	35	31	84	274
29185	497	79	5000	0.17	3000	1200	16	7.7	42	129
29186	7	0.3	8000	0.005	17000	23400	9.6	6.1	7	65
29187	360	58	6000	0.21	5000	2800	14	8.5	58	54
29188	8.4	0.17	10000	0.002	15000	27200	8.2	5.8	33	126
29189	19	1.1	24000	0.002	16000	19300	27	27	47	198
29190	28	2.5	23000	0.008	12000	15600	24	42	102	290
29191	116	6.2	28000	0.06	18000	9170	34	30	123	238
29192	11	0.21	13000	0.003	16000	23700	16	13	30	112
29193	39	3.3	6000	0.004	1100	470	13	14	30	10
29194	144	5.5	38000	0.02	10000	11100	37	59	136	903
29195	7.2	0.31	28000	0.004	5000	3700	31	35	61	402
29203	2125	140	49000	2.03	27000	11000	66	57	200	716
29205	2278	99	68000	1.78	14000	6200	1228	64	659	706
29206	87000	5000	139000	35	78000	5600	1774	433	2420	1125
29208	8158	484	15000	15.3	10000	6160	172	11	84	124
29211	21500	10700	171000	9.1	3000	72000	510	240	2543	595
29213	5462	204	68000	6.44	14000	3830	112	75	393	1455
29221	5144	185	76000	2.75	12000	8300	115	92	432	1169

Table 8-2. Soil sample descriptions from all samples analyzed in 2000 field season. Refer to other documents for further sample descriptions.

Sample Number	Location	Area	Field Duplicate	Surface Tag Number	Depth [cm]	Sample Description
29072	pump house	Great Slave Cruising Club			0-10	grey gravel sand/fill
29073	pump house	Great Slave Cruising Club		29072	20-25	greenish grey clay mixed with gravel
29074	next to building	Great Slave Cruising Club			0-10	consistent brown clay with red brown streaks
29075	between boats	Great Slave Cruising Club			0-10	medium brown sand with rocks
29076	forested area	Great Slave Cruising Club			3-7	clay
29077	forested area	Great Slave Cruising Club		29076	10-20	till/fine sand, organic at 7-10cm
29078	Niven Lake Residential	City			0-10	medium to light brown sand with gravel
29079	Doornbos Park	City	29080		0-20	sand
29080	Doornbos Park	City	29079		0-20	sand
29081	School Draw Park	City			0-20	sand
29126	Con Mine playground (sandbox)	Con Mine town site			0-15	medium brown sand with scattered gravel
29178	North point, NE side	Ndilo			0-10	black organic
29179	W side, end of culvert ac. 213	Ndilo			0-10	black/dark brown organic with roots
29180	W side, end of culvert ac. 213	Ndilo			0-10	black/dark brown organic with roots
29181	North point, NW side	Ndilo			0-15	black organic/humic, wet, roots, boggy
29182	N of boat launch (200 lot)	Ndilo			0-15	medium brown sand with small cobble
29183	SW end, between 99 lot and road	Ndilo			0-7	black organic with root
29184	Turner road, 6 lot	Ndilo			0-10	black sand with some root, gravel
29185	Top of hill, E side	Ndilo			0-7	humic and black organic
29186	Older Playground	Ndilo			0-15	light brown sand
29187	S border, part of 909 lot	Ndilo			2-10	black organic
29188	N of dock, behind firehall	Dettah			0-15	large cobble and medium brown sand
29189	SW part, btwn LL andMM	Dettah	29190		0-7	dark brown with root
29190	SW part, btwn LL andMM	Dettah	29189		0-7	dark brown with root
29191	SE part, near W and dock at cul-de-sac	Dettah			0-8	black/brown organic with roots
29192	playground behind school	Dettah			0-10	sand with few threads of blue rope
29193	NE part, between S and R	Dettah			2-15	black oganic with lots of roots
29194	On hill, near K and J	Dettah			0-7	black organic with fractured bedrock
29195	W side of main road, N part	Dettah			0-10	wet sandy gravel
29203	Assay office	Giant Mine			0-10	grey clay
29205	Reagent warehouse	Giant Mine			0-10	grey brown fill
29206	Next to Roaster	Giant Mine			0-10	white residue on top 5mm, red brown sandy clay
29208	Next to baghouse	Giant Mine			0-10	light brown sand
29211	E of Mill	Giant Mine			0-10	red brown sand
29213	Under overhead conveyer	Giant Mine			0-10	rock from crusher
29221	Next to main office parking lot	Giant Mine			0-10	grey gravel sand/fill

Precision/Repeatability

External monitoring of precision was performed by the analysis of soil sample field duplicates. These samples were homogenized in the field and then split and submitted blind to the laboratory for analysis. Four soil field duplicates from were analyzed and results are presented in Table 8-5. Average relative standard deviations or coefficients of variation (standard deviation divided by the mean) for sample pairs were expressed as percentages and used to evaluate laboratory precision. Acceptable limits are generally considered to be less than 30% relative standard deviation, with 20% or less considered good agreement. Four were analyzed average relative standard deviations for copper (11%), nickel (13%) and manganese (9.5%) were below 20% indicating good agreement between duplicates. Zinc was just above the good agreement level but within the acceptable level at 25%.

Internal monitoring of precision was carried out by ASU through the use of analytical replicates. Six soil samples were analysed in duplicate (Table 8-6). Average relative standard deviations for nickel, zinc, and manganese were below 10%, indicating excellent agreement. The average RSD for copper (18%), although higher, was still within a level considered for good agreement.

QA/QC for Inorganic Analysis by Neutron Activation Analysis – Royal Military College Analytical Services Group (ASG)

Accuracy

Accuracy was monitored internally by ASG using NRC Canada Marine Reference Sediment MESS-2 and GSS5 soil from the Peoples Republic of China. Six reference standards were analyzed for arsenic, antimony, iron, gold, sodium and potassium (Table 8-3). These were run concurrently with sample batches throughout the analytical program. Good agreement with the certified values was obtained for all elements.

Six blank samples were run with the soil samples and results are presented in Table 8-4. All elements in the blanks were consistently below detection limits.

Precision/Repeatability

Precision was monitored externally by ESG using four pairs of soil sample duplicates; these were homogenized in the field and submitted blind as separate samples to ASG for analysis. The results are presented in Table 8-5. Average relative standard deviations for five of the six elements were below 30%, indicating satisfactory agreement. Antimony

Table 8-3: Summary of Inorganic Analysis Results for Soil Internal Standards.

Element	MESS-2 Certified Value	NAA Results Determined Value (n=6)	GSS5 Certified Value	NAA Results Determined Value (n=6)	ICP-OES Results Determined Value (n=6)
As [ppm]	20.7	22±1.1	412	427±13	
Sb [ppm]	1.09	1.2±0.3	35.4	40±4.1	
Fe (%)	4.35	4.6±0.21	8.8	8.8±0.1	
Au [ppm]		<0.01		0.26±0.04	
K (%)			1.2	1.2±0.1	
Na (%)			905	725±78	
Cu [ppm]	39.3				33 ±1.1
Ni [ppm]	49.3				40 ± 1.0
Zn [ppm]	172				149 ±5.7
Mn [ppm]	365				307 ± 17

Table 8-4. Summary of Blank Analysis Results for Soils.

	As [ppm]	Sb [ppm]	Au [ppm]	Fe(%)	K (%)	Na (%)	Cu [ppm]	Ni [ppm]	Zn [ppm]	Mn [ppm]
Blank	<0.05	<0.2	<0.003	<0.3	<0.6	<0.05	<3.0	<5.0	<15	<10
Blank	<0.05	<0.2	<0.003	<0.3	<0.6	<0.05	<3.0	<5.0	<15	<10
Blank	<0.05		<0.003	<0.3	<0.6	<0.05	<3.0	<5.0	<15	<10
Blank	<0.05	<0.2	<0.003	<0.3	<0.6	<0.05	<3.0	<5.0	<15	<10
Blank	<0.05	<0.2	<0.003	<0.3	<0.6	<0.05	<3.0	<5.0	<15	<10
Blank	<0.05	<0.2	<0.003	<0.3	<0.6	<0.05	<3.0	<5.0	<15	<10

Table 8-6. Lab Duplicate Samples for Inorganic Analysis

Sample Number	As	Sb	Fe	Au	K	Na	Cu	Ni	Zn	Mn
	ug / g	ug / g	ppm	ug / g	% by weight	% by weight	ug / g	ug / g	ug / g	ug / g
29022	3.91	0.76	1.49	< 0.0040	1.67	2.357	7.9	7.7	15	95
29022, Dup	3.74	0.161	1.04	< 0.0034	1.64	2.414	7.6	7.6	16	95
Average	3.83	0.46	1.27	N/A	1.66	2.39	7.72	7.67	15.77	N/A
Standard Deviation	0.12	0.42	0.32	N/A	0.02	0.04	0.19	0.07	0.41	N/A
Relative Std Dev (%)	3.14	91.98	25.15	N/A	1.28	1.69	2.51	0.92	2.62	N/A
29078	40.63	1.05	2.43	< 0.007	1.86	3.071	19.1	18.6	28	188
29078 Dup	28.98	0.754	1.89	< 0.0085	1.65	2.379	18.8	18.4	26	192
Average	34.81	0.90	2.16	N/A	1.76	2.73	18.95	18.50	26.91	189.62
Standard Deviation	8.24	0.21	0.38	N/A	0.15	0.49	0.25	0.10	1.25	2.66
Relative Std Dev (%)	23.67	23.20	17.68	N/A	8.46	17.96	1.31	0.52	4.64	1.40
29183	227	54	1.5	0.25	0.6	0.92	29.3	15.8	186	978
29183 Dup	224	59	1.5	0.28	0.5	0.92	26.9	15.1	184	928
Average	225.50	56.50	N/A	0.27	0.55	N/A	28.11	15.47	185.22	953.20
Standard Deviation	2.12	3.54	N/A	0.02	0.07	N/A	1.70	0.52	1.43	35.25
Relative Std Dev (%)	0.94	6.26	N/A	8.00	12.86	N/A	6.03	3.39	0.77	3.70
29189	17.51	1.049	2.4	< 0.0054	1.37	1.968	12.7	26.1	43	189
29189 Dup	20.12	1.08	1.08	< 0.0051	1.89	1.89	40.7	27.9	50	208
Average	18.82	1.06	1.74	N/A	1.63	1.93	26.67	27.02	46.56	198.45
Standard Deviation	1.85	0.02	0.93	N/A	0.37	0.06	19.77	1.24	5.11	13.58
Relative Std Dev (%)	9.81	2.06	53.64	N/A	22.56	2.86	74.15	4.61	10.97	6.84
29193	Not run in Dup	Not run in Dup	Not run in Dup	Not run in Dup	Not run in Dup	Not run in Dup	12.9	13.1	29	11
29193 Dup							14.1	14.1	32	10
Average							13.49	13.62	30.06	10.40
Standard Deviation							0.80	0.69	2.19	0.64
Relative Std Dev (%)							5.91	5.10	7.30	6.14
Average RDS	**9.39**	**30.87**	**25.00**	**8.00**	**11.29**	**7.50**	**17.98**	**2.91**	**5.26**	**4.52**

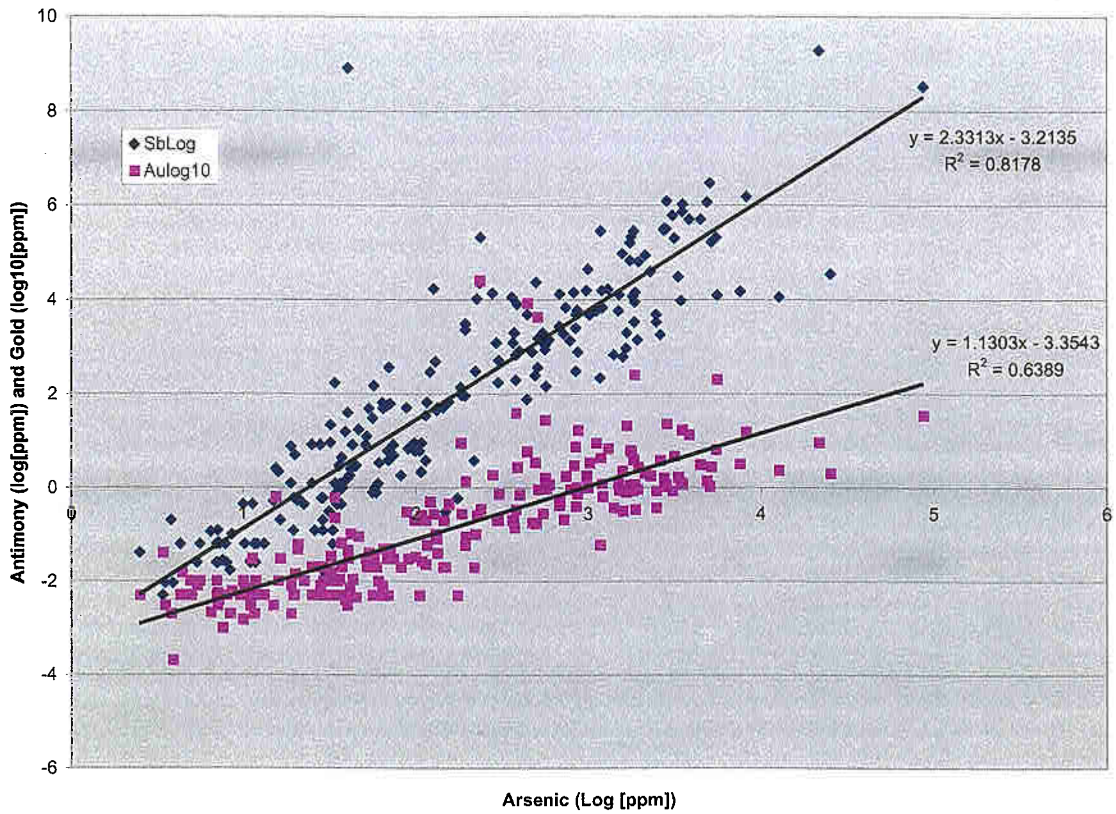

Figure 8-1. Linear regression between arsenic and the two elements antimony and gold.

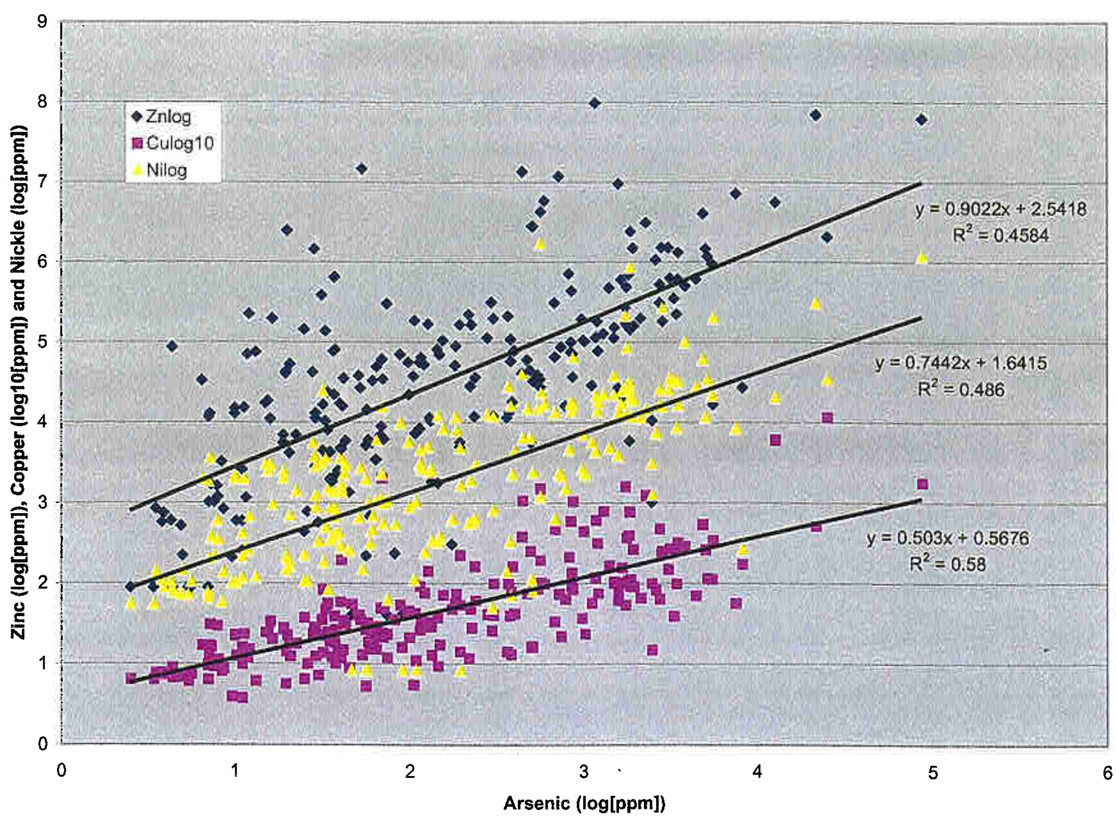

Figure 8-2. Linear regression between arsenic and the three elements zinc, copper and nickel.

Table 8-7. All soils, sediments and tailings locations in PCA and Ttest

Green Ellipse		Red Ellipse		Below -1 on Y Axis		outliers	
Sample Location	As [ppm]	Sample Location	As [ppm]	Sample Location	As [ppm]	Sample Location	As [ppm]
1G	6	10G	278			29206	87000
26G	65	16G	1764	1	61	29208	8158
29G	114	17G	1946	2	37	29211	21500
3	56	18G	2838	13	74	35	25000
4	58	19G	3821	20	54	29180	780
5	8	20G	1736	34	121	84	68.6
6	26	21G	1193	39	57		
7	33	22G	1825	43	506		
8	29	23G	88	44	372		
9	7	24G	41	45	294		
10	105	25G	302	48	82		
11	5	27G	738	51	47		
12	31	28G	974	52	34		
14	20	30G	3494	54	443		
15	35	30G	238	55	379		
16	37	31G	4842	56	193		
17	51	32G	3072	57	90		
18	148	33G	1738	67	676		
19	4	34G	2808	68	235		
21	12	35G	2740	83	108		
22	59	36G	2730	97	387		
23	107	37G	3301	108	99		
24	38	38G	3480	29178	194		
25	20	39G	4431	29181	560		
26	11	3G	1016	29185	497		
27	13	44G	1919	29187	360		
28	11	45G	1643	29193	39		
29	33	4G	3140				
30	42	8G	194				
31	133	33	7500				
32	16	36	12600				
40	29	37	1165				
42	300	38	69				
46	174	41	2472				
47	114	49	5028				
62	21	50	3433				
69	218	53	2461				
70	74	58	1580				
71	30	59	591				
73	12	60	566				
74	10	61	41				
86	61	63	1860				
88	16	64	994				
94	130	65	850				
99	11	66	717				
100	21	72	29				
101	98	75	2600				
103	40	76	1400				
105	25	77	491				
106	10	78	865				
107	38	79	560				
29012	3	80	440				
29013	4	81	1660				
29014	3	82	1840				
29015	9	85	5550				
29016	4	87	182				
29017	4	89	380				
29018	4	90	1110				
29019	5	91	1571				
29020	5	92	1175				
29021	6	93	681				
29022	4	95	1300				
29023	132	96	840				
29024	7	98	820				
29025	29	102	155				
29033	16	104	184				
29038	23	29047	127				
29046	7	29053	1800				
29049	10	29055	222				
29050	10	29056	1204				
29051	32	29057	366				
29052	15	29058	1850				
29054	45	29063	1500				
29059	71	29064	1490				
29060	68	29065	544				
29061	40	29071	845				
29062	37	29072	471				
29066	145	29073	861				
29067	36	29179	510				
29068	32	29183	226				
29069	25	29203	2125				
29070	20	29205	2278				
29074	19	29213	5462				
29075	43	29221	5144				
29076	56						
29077	64						
29078	35						
29079	12						
29080	8						
29081	8						
29126	7						
29182	34						
29184	52						
29186	7						
29188	8						
29189	19						
29190	28						
29191	116						
29192	11						
29194	144						
29195	7						
mean	41.9	mean	1687	mean	231		
std dev	50.6	std dev	2173	std dev	194		
median	25.5	median	994	median	157		
range	2.5-300	range	29-12600	range	34-676		