

**Sampling & Analysis  
of  
Snow Cores**  
Yellowknife Region, N.W.T.  
Volume 1

*Prepared for*

Environmental Protection Division  
Department of Renewable Resources  
Government of the Northwest Territories  
Yellowknife, N.W.T.

Project No. S-4901

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Project No. 94-0260

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Our File No.: 94-0260

24 June, 1994

Environmental Protection Division  
Department of Renewable Resources  
Government of the N.W.T.  
Yellowknife, N.W.T.

Attention: Mr. Jim Sparling

Re: Sampling and Analysis of Snow Cores  
Yellowknife, N.W.T.

Dear Sir,

We are pleased to present our report on the 1994 snow core sampling and analysis program. During this program snow cores were extracted at various locations in the Yellowknife area and analyzed for arsenic, pH and sulphate.

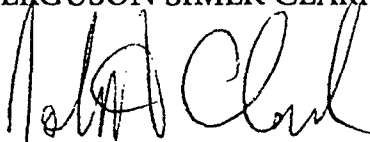
The analytical results were compared with the results of similar studies in 1975 and 1986.

We have included a section of recommendations for future studies. We believe that the most important of these is development of a standard methodology for sampling, sample handling, laboratory analysis and quality assurance/quality control. We would be available to assist in the development of the standard methodology.

We appreciate the opportunity to assist you in this work. It has been a most interesting project.

We are available to discuss the report at your convenience.

FERGUSON SIMEK CLARK



John A. Clark, P.Eng.

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## 1.0 Abstract

Ferguson Simek Clark and Arctic Environmental Services were contracted by the Environmental Protection Division of the Government of the Northwest Territories to conduct a snow sampling program, in the vicinity of the City of Yellowknife, specifically designed to measure the arsenic deposition rates over a defined course of time.

The sampling program was carried out during the spring of 1994, with results indicating an increase in the arsenic deposition rates as compared to a similar study carried out in 1986 for the Pollution Control Division of the Government of the Northwest Territories.

## 2.0 Introduction

### 2.1 General

Yellowknife is located on the west shore of Yellowknife Bay on the North Arm of Great Slave Lake in the Northwest Territories. Gold was discovered in the Yellowknife area in 1896 and as a result a staking rush began in the early 1930's. The City of Yellowknife grew out of the gold mining industry and today there are two gold producing mines in the immediate vicinity of the city; these are Royal Oak Mines Giant Mine and Miramar Con Mine.

Arsenic, while relatively uncommon in nature, occurs naturally in the gold bearing ores of the Yellowknife area. Arsenic in the Yellowknife area occurs predominantly as arsenopyrite ( $\text{FeAsS}$ ). Arsenopyrite is a major ore of arsenic occurring as prismatic crystals or columnar and granular masses.

A method of extracting gold from gold rich ore concentrate is to "roast" the ore to free the sulfur. The resulting product is a porous material which is then treated with cyanide to leach the gold. Finally the gold is precipitated from the cyanide solution and recovered.

A byproduct of roasting is that it volatilizes the arsenic and releases it with the waste gases produced by the process. Abatement procedures have been established at many roasting operations. Such procedures include the installation of electrostatic precipitators and "baghouses" which filter and collect the arsenic prior to its release to the environment. Abatement procedures are not 100% effective, therefore some arsenic continues to enter the environment in the vicinity of such operations.

Royal Oak Mines Giant Mine utilizes a roasting procedure complete with an electrostatic precipitator and baghouse in its gold recovery process. Royal Oak Mines arsenic emission abatement equipment has been continually upgraded since its initial installation in 1951.

Other means of reducing the gold concentrate are utilized by various operations which do not include the roasting process. Miramar Con Mine utilized a roaster until November 1970 at which time they abandoned the process opting for a chemical reduction process.

While the abandonment of Con's roaster has reduced the gaseous emissions of arsenic in the Yellowknife area, fugitive emissions of arsenic remain a part of the process including arsenic contents in the slurry wasted to the tailings ponds on the property.

## 2.2 Previous Studies

This study is primarily a comparative program relating to two past studies carried out specifically for the purpose of measuring arsenic contamination by snow sampling programs. The most relevant past studies are as follows:

*"Chemical Characteristics of Snow in the Yellowknife Area, NWT, 1975"*  
(Environmental Protection Service, Environment Canada, 1977).

and

*"Sampling and Analysis of Snow Cores in the Yellowknife Area, April 1986."* (Stanley Associates Engineering Ltd.) for the Pollution Control Division, Government of the Northwest Territories.

A third study reviewed during the writing of this report was one prepared specifically concerning emissions from the Royal Oak Giant Yellowknife Mine. This report is titled as follows:

*"An Investigation of Atmospheric Emissions from the Royal Oak Giant Yellowknife Mine"* (Environmental Protection Division, Dept. of Renewable Resources, GNWT, June 1993)

The 1977 Environment Canada Study was carried out by collecting snow cores and scoop samples during the spring of 1975 as part of an overall Yellowknife Environmental Survey. The prime objectives of the survey were as follows:

1. *To quantify the concentration of arsenic in melted snow water.*
2. *To assess deposition rates of arsenic during the winter.*

The conclusions of this program were as follows:

1. *The Canadian Drinking Water Standards (CDWS) (current at that time) maximum permissible arsenic levels were generally exceeded within the sample group collected in the Yellowknife area.*
2. *The estimated mean deposition rate of arsenic in the vicinity of Yellowknife was  $1.9 \text{ kg/km}^2 \cdot \text{month}^{-1}$ .*
3. *The geometric mean arsenic concentration in melted snow samples was  $170 \text{ } \mu\text{g/L}$ .*
4. *The pH of snow within the vicinity of Yellowknife was generally lower than the acceptable level of 6.5 specified by the CDWS.*

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<sup>1</sup> The values  $1.9 \text{ kg/km}^2 \cdot \text{month}$  and  $2.23 \text{ kg/km}^2 \cdot \text{month}$  are both used in the 1986 report. Reference to the original report is to  $0.0053 \text{ tons/mile}^2 \cdot \text{month}$  ( $1.86 \text{ kg/km}^2 \cdot \text{month}$ ).

The intent of the 1985 Stanley Associates Engineering Study was to pattern the 1975 testing program as closely as possible in order to provide a comparative analyses between the programs and results. The prime objectives of the survey were as follows:

1. *To assess changes in depositions of arsenic in the Yellowknife area as a result of the introduction of emission abatement equipment at the Giant Yellowknife Mines Ltd. gold roasting operation.*
2. *To determine present concentrations of sulphates and pH values of snow cores samples as an initial step in examining sulphur dioxide emissions in the area.*
3. *To analyze a number of samples, randomly selected, for sulphite.*

The conclusions of this program were as follows:

1. *The geometric mean arsenic concentration in melted snow samples was 0.028 mg/L (28 µg/L), representing a reduction of 84% in the geometric mean arsenic concentrations in the Yellowknife area in 1986 compared to 1975.*
2. *The geometric mean of the arsenic deposition rate on the Study Area in 1986 was 0.40 kg/km<sup>2</sup>.month. This rate represented approximately 18% of that in 1975 which was 2.23 kg/km<sup>2</sup>.month.<sup>1</sup>*
3. *The percentage of samples exceeding the Canadian Drinking Water Standard for arsenic concentrations (50 µg/L) was reduced from 83 % in 1975 to 33% in 1986.*
4. *There was no significant difference between sulphate levels measured in the city of Yellowknife and in the vicinity of the Royal Oak Mines Giant Mine property.*
5. *Sulphite levels in the snow samples were below the detectable limit of 0.5 mg/L.*

<sup>1</sup> Based on 1975 value of 1.9 kg/km<sup>2</sup>.month the 1986 rate was 21% of the 1975 rate.



The intent of the 1993 Environmental Protection Division investigation was to measure levels of arsenic and sulphur dioxide resulting from roaster stack emissions and determine the impact on vegetation. The prime objectives of the investigation were as follows:

1. *To determine the roaster stack emission rates for arsenic and SO<sub>2</sub>.*
2. *To determine the fate of arsenic and SO<sub>2</sub> dispersed to the environment and estimate the concentrations and total loading within the dispersal zone.*
3. *To determine the cause of vegetation damage observed in the vicinity of Royal Oak Giant Yellowknife Mine.*

The conclusions of this investigation were as follows:

1. *Emission rates were 20 to 30 kg/day for arsenic and 50 to 65 tonnes/day for sulphur dioxide.*
2. *Total arsenic levels in Yellowknife air were below the Ontario 24 hour average limit of 0.3 µg/m<sup>3</sup>.*
3. *Ambient concentration levels of SO<sub>2</sub> in Yellowknife air periodically exceeded the National Air Quality Objective Maximum Desirable Level of 450 µg/m<sup>3</sup> for a one hour period. These occurrences usually last for a short period only.*
4. *Damage to trees from high levels of SO<sub>2</sub> was found along the Vee Lake Road as far as 5 kilometres north of the roaster stack.*

### 3.0 Program Objectives

The objectives of the current 1994 Program included the following:

1. *The development of a snow collection and analyses scheme which would provide a comparison with past measured concentrations of arsenic in melted snow water and deposition rates of arsenic during the winter by measuring the cumulative amount of arsenic entrapped in the snow.*
2. *The analysis of the samples for sulphate.*
3. *The analysis of the pH levels for the sample series.*

In order to collect a comparative set of samples, the collection locations for the sampling programs carried out by the 1976 Environment Canada Study and the 1986 Stanley Associates Engineering Study were replicated as closely as was possible.

#### 4.0 Sampling Program

Ferguson Simek Clark personnel undertook the sampling program between the 14 th and 16 th days of March 1994. Fifty five (55) samples were collected at forty five (45) separate locations by means of a "coring" tool. This tool was fabricated out of section of 100 mm diameter ABS plastic pipe.

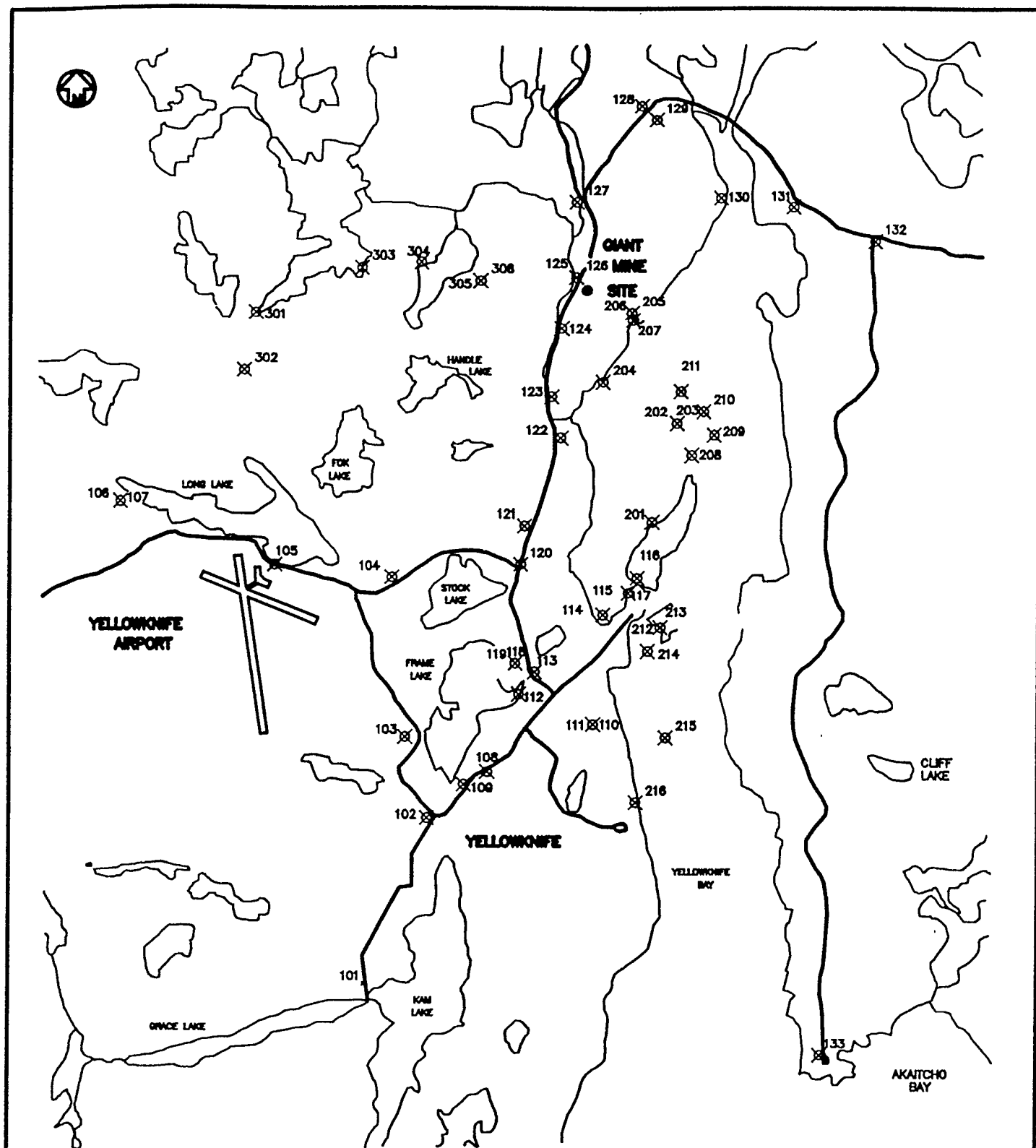
The samples were double bagged in plastic zip top sample bags, evacuated, labeled and delivered to the contract laboratories. The samples were shipped to the laboratories in a frozen state with melting allowed to take place once at the respective labs.

Stanley Associates Engineering 1986 sampling program included dividing the cores into three vertical sections. It was agreed with the Department of Renewable Resources prior to this sampling program that there was little benefit gained by subdividing the previous samples and that composite samples would satisfy the program requirements.

The samples were collected by vertically inserting the tool to the base of the snow column. The snow about the perimeter of the tool was then shoveled clear in order to facilitate the removal of the sample. A shovel was then inserted below the tool to retain the sample during its extraction.

The bottom section of approximately 50 mm was discarded to reduce the possibility of contamination and the remaining sample was "poured" into the sample bags. The samples were shipped free of preservative and algicide.

Single samples were taken at thirty six of the sampling points. Double samples were retrieved at eight locations and at one sampling point a set of three samples was collected. The primary set of forty five (45) samples was sent to the Indian & Northern Affairs Water Resources Laboratory (DIAND) in Yellowknife for analysis and as a measure of quality control and assurance, the nine matched samples were sent to Norwest Laboratories in Edmonton for an independent analysis.



DRAWING TITLE

# SNOW SAMPLE LOCATION PLAN

JOB TITLE

## YELLOWKNIFE SNOW SAMPLING

JOB NUMBER

94-0260

FERGUSON, SIMEK, CLARK  
CONSULTING ENGINEERS & ARCHITECTS

DESIGNED BY  
KH

SCALE  
NTS

DRAWN BY  
PW

DATE  
30 MAY 1994

CHECKED BY

DRAWING NO  
Figure 1

P.O. BOX 1777 YELLOWKNIFE  
N.W.T., CANADA X1A2P4

The program for the point at which three samples were collected included two of those being sent independently to the DIAND laboratory for analyses and the third being sent to Norwest Laboratory.

Sampling points were selected clear of drifted areas in an effort to achieve the most representative samples.

Transportation to the sampling points was by truck to the locations adjacent to roadways and by snowmobile to the points inaccessible by road.

All samples were successfully transported to the laboratories for analyses within 24 hours of collection of final sampling. They were confirmed to be in a frozen state upon delivery to the laboratories, and standard chain of custody protocols were maintained.

## 5.0 Laboratory Chemical Analysis

The collected samples were allowed to melt to room temperature once received by the respective laboratories and the following programs were carried out:

DIAND Water Resources Laboratory	<i>pH</i> <i>Sulphate</i> <i>Total Arsenic</i>
Norwest Laboratories	<i>Total Arsenic</i>

The data received from the laboratories are compiled and presented in Table 1 of this report and a copy of the original laboratory transmittals are appended in Section 10.0, Volume 2.

The total arsenic levels in the samples analyzed by Norwest Laboratories were determined utilizing comparable analytical techniques as the Water Resources Laboratory for total arsenic (perchloric acid digest, and automated hydride atomic absorption spectroscopy; American Public Health Association reference APHA 3114 C). The analyses carried out were in accordance with "Standard Methods for the Examination of Water & Wastewater" 17 th edition APHA).

The total arsenic levels in the samples analyzed by the Water Resources Laboratory were determined utilizing atomic adsorption with hydride generation (TAs\_H NAQUADAT #33011). Aliquots of preserved samples and standards were manually digested with  $\text{H}_2\text{SO}_4$ ,  $\text{HNO}_3$ , and  $\text{HClO}_4$ . Arsenic was reduced to arsine with  $\text{NaBH}_4$  in acidic solution and was then sparged into a heated quartz combustion tube which decomposed the hydride to form arsenic atoms. The absorption is measured spectrophotometrically at 193.7 nm. Method detection limit =  $0.3 \mu\text{g/L}$ .

pH was analyzed by the Water Resources Laboratory by NAQUADAT variable code #10301 utilizing the electrometric method. The pH was measured utilizing a calibrated meter with a detection limit = 0.05 pH units.

Sulphate was analyzed by the Water Resources Laboratory by NAQUADAT variable code #16306 utilizing a colourimeter. The detection limit for this method was 3.0 mg/L.

Backup information provided by the laboratories involved in this testing program is appended in Section 10.0, Volume 2 of this report.

## 6.0 Data Analysis

### 6.1 Arsenic Evaluation

The new Interim Maximum Acceptable Concentration (IMAC) is 25  $\mu\text{g/L}$  from the previous value of 50  $\mu\text{g/L}$  Maximum Acceptable Concentration (MAC) found in the Canadian Drinking Water Standards (CDWS), 5<sup>th</sup> ed., 1993.

The concentrations of arsenic in 34 of the 55 or 62 % of the samples collected in this program exceeded the specified allowable concentration of 50  $\mu\text{g/L}$  as defined by CDWS. (For comparative reasons, the CDWS for arsenic used in 1975 and 1986 was also utilized in the current 1994 study).

Of these samples exceeding the acceptable level, 19 measured one order of magnitude greater and two measured two orders greater than the acceptable limit. The geometric mean of the total arsenic concentration for the 1994 sample group was 98.9  $\mu\text{g/L}$  compared with the 1986 result of 28  $\mu\text{g/L}$  and the 1975 result of 170  $\mu\text{g/L}$ .

Arsenic concentration levels are represented on Tble 1 and Figure 2 of this report.

The arsenic concentrations are dependent on the dilution provided by the seasonal snow fall. A more representative figure for analyses is the deposition rate as measured in mass/(unit area · time). The mass of arsenic for each sample location was calculated by multiplying the concentration of total arsenic, as reported by the laboratories, by the volume of the sample. The area component of the equation was determined based upon the tool having an interior diameter of 100 mm.

The time component of the equation was calculated based upon information received from Environment Canada, Atmospheric Environment Service in Yellowknife. It was reported that the date that the snow pack first exceeded 50mm in the 1993/94 winter was November 4<sup>th</sup>. The sampling program was carried out between March 14<sup>th</sup> and 16<sup>th</sup>. The duration of time during which the snowfall was deposited therefore was 4.4 months.



As an example, the arsenic deposition rate for sample number 101 in kg/km<sup>2</sup>·mo was calculated as follows:

$$\text{Total Arsenic Concentration } (\mu\text{g/L}) \times \text{Sample Volume (L)} = \text{Arsenic Mass } (\mu\text{g})$$

$$19.0 \mu\text{g/L} \times 0.25 \text{ L} = 4.75 \mu\text{g}$$

$$\text{Arsenic Mass } (\mu\text{g}) \times 1 \times 10^{-9} (\mu\text{g/kg}) = \text{Arsenic Mass (kg)}$$

$$= 4.75 \times 10^{-9} \text{ kg}$$

$$\text{Sampling area} = \frac{\pi d^2}{4} = \frac{\pi (100 \text{ mm})^2}{4} = 7,850 \text{ mm}^2 = 7.85 \times 10^{-9} \text{ km}^2$$

$$\text{Deposition Time} = (94-03-15 - 94-11-04) = 4.4 \text{ months}$$

Therefore the Total Arsenic Deposition Rate for sample number 101 is as follows:

$$= \frac{4.75 \times 10^{-9} \text{ kg}}{(7.85 \times 10^{-9} \text{ km}^2) \times (4.4 \text{ month})} = 0.14 \text{ kg/km}^2 \cdot \text{month}$$

The geometric mean of the deposition rate for this study series was 1.37 kg/km<sup>2</sup>·mo as compared with the Stanley Associates Engineering' 1986 study value of 0.40 kg/km<sup>2</sup>·mo and the 1977 Environment Canada Study value of 1.86 kg/km<sup>2</sup>·mo.

Arsenic deposition isopleths are represented on Figure 3 of this report.

The locations with the greatest arsenic contamination are in the vicinity of the Royal Oak Mines Giant Mine property.

The arsenic detection limits for the sampling programs were provided by the laboratories. The Arsenic detection limit reported by the Water Resources Laboratory was 0.3 μg/L (total arsenic in water). The detection limit reported by Norwest Laboratory was 0.2 μg/L (total arsenic in water).

For Quality Control purposes, samples were taken at adjacent locations at 9 sampling points. The samples were analyzed by both Norwest Labs and the Water Resources Laboratory. The Norwest Laboratory results were approximately one third higher in all cases but one. This discrepancy may be due to the fact that the samples handling required multiple dilutions because of the high concentration of arsenic in the samples.

The analytical ranges at the two labs were Norwest (0.2 - 8.0 µg/L) and for the Water Resources Laboratory (0.3 - 100 µg/L). In the case of samples 125 and 126, the samples were diluted up to 500 fold in order to get them within detectable ranges. This would possibly explain the discrepancy.

## 6.2 pH Evaluation

pH levels recorded in the 1994 program were generally less than the recommended level for drinking water. The level recommended by the Canadian Drinking Water Standards and Objectives is between 6.5 and 8.5. The geometric mean pH level measured in the 1994 sample group was 6.17 with values varying between 4.78 and 8.35.

The program results are compiled and represented in Table 1 of this report.

In comparison, the 1986 report noted that pH ranged from 4.8 – 8.3 and was generally below the CDWS range of 6.5 – 8.5. The 1975 report also noted that the pH of snow samples was also low, and generally outside the acceptable range in the CDWS, ranging from 3.20 to 8.80.

## 6.3 Sulphate Evaluation

Sulphate concentrations were analyzed by the Water Resources Laboratory. The detection limit of 3.0 mg/L, quoted by the laboratory for the colorimeter, was not acceptable for this study. The analysis was carried out by automatic colourimetric techniques. NAQUADAT variable code #16306.

This analysis in future studies should be done using ion chromatography. We would expect variation below the detection limit of 3.0 mg/L in this study as was demonstrated in the 1985 study.

The program results are compiled and represented in Table 1 of this report.

The 1985 report noted sulphate concentrations were generally low, ranging from 0.5 mg/L to 3.0 mg/L. It also noted that sulphate deposition rates in the Yellowknife area (30 kg/km<sup>2</sup>·month) were considerably lower than values typical of an industrial/urban area (70 – 350 kg/km<sup>2</sup>·month).

Average sulphate concentrations in the 1985 report were 2.2 mg/L in the City of Yellowknife, 1.1 mg/L near the Giant operation and 1.3 mg/L on the periphery of the study area.

#### 6.4 Quality Assurance/Quality Control

There seems to be a variation of about 33% between the study data and samples sent to Norwest Labs. This could be explained as a systematic error possibly due to dilution factors. The analytical ranges used on the instrumentation for analysis were 0.2 – 8.0 µg/L for Norwest Labs and 0.3 – 100 µg/L for the Water Resources Laboratory. It is difficult to get good laboratory results when dilution factors of up to 500 are necessary to get results on the instrument scale. (All samples in this study were high and required dilution).

It is common to have differences between laboratories because of different operators, analytical equipment and operating procedures. This particular work could be considered non-routine and perhaps more discussion could have taken place prior to analysis to standardize the methodology.

Quality Control information was provided by the laboratories but it only accounts for instrumental variation and does not take into account all the controlling factors found in a field study, which can also include variability in concentrations of arsenic from sample locations in close proximity. Nevertheless, we have confidence in the data trends found in this study.

The Water Resources Laboratory which did the bulk of the testing reports analytical accuracy of 112 – 114% on the quality control runs. From this it is inferred that reported results should be within 80% to 120% of actual values.

4.4 months

Table 1 - Compiled Data  
Sampling & Analysis of Snow Cores - Yellowknife Region

Sample Number	SAEL Site	Sample Date	Location	UTM Coordinates		Testing Lab.	pH	Arsenic (µg/L)			Sulphate (mg/L)	As Deposition Rate (kg/km2/month)		
				Northing	Eastings			1994	1986	1975		1994	1986	1975
101	60	94-03-14	Kam Lake Road	6 923 993	633 335	DIAND	6.58	19.0	9.0	100.0	n.d.	0.14	0.17	1.12
102	12	94-03-14	South of Pumphouse 4	6 926 070	634 128	DIAND	6.80	83.6	11.0	60.0	3.0	0.61	0.19	0.67
103	11	94-03-14	NE of Stanton View Mall	6 927 107	633 850	DIAND	6.56	22.9	9.0	70.0	n.d.	0.40	0.18	0.78
104	10	94-03-14	Fred Henne Park Entr.	6 929 135	633 679	DIAND	6.28	67.2	36.0	60.0	n.d.	0.69	0.58	0.67
105	9	94-03-14	Opposite Airport Parking Lot	6 929 301	632 192	DIAND	6.42	36.3	23.0	100.0	n.d.	0.26	0.28	1.12
106	8	94-03-14	N End Long Lake	6 930 106	630 236	Norwest		62.6	7.0	60.0		0.86	0.13	0.67
107	8	94-03-14	N End Long Lake	6 930 106	630 236	DIAND	4.97	68.5			n.d.	0.90	0.13	0.67
108	14	94-03-14	SE of Pumphouse 3	6 926 660	634 885	DIAND	6.36	36.8	13.0	20.0	n.d.	0.64	0.22	0.22
109	13	94-03-14	S Side of Franklin Ave by Lanky Ct.	6 926 501	634 597	DIAND	6.91	62.9	21.0	50.0	3.1	0.92	0.34	0.56
110	16	94-03-14	E of Sir John Franklin HS	6 927 263	636 213	DIAND	6.32	58.5	22.0	50.0	n.d.	0.68	0.36	0.56
111	16	94-03-14	E of Sir John Franklin HS	6 927 263	636 213	Norwest		140.0				1.31	0.36	0.56
112	15	94-03-14	W of City Hall	6 927 642	635 283	DIAND	6.07	24.4	16.0	90.0	n.d.	0.32	0.25	1.01
113	17	94-03-14	N of Explorer Hotel	6 927 921	635 484	DIAND	5.65	29.9	16.0	50.0	n.d.	0.44	0.30	0.56
114	29	94-03-14	S End of Back Bay	6 928 644	636 332	DIAND	4.78	47.1	22.0	70.0	n.d.	0.55	0.42	0.78
115	29	94-03-14	S End of Back Bay	6 928 644	636 332	Norwest		72.6			n.d.	1.42	0.42	0.78
116	30	94-03-14	SW Shore Latham Island	6 929 125	636 765	DIAND	5.61	58.9		200.0	n.d.	0.77		2.24
117	31	94-03-14	Max Ward's Float Base	6 928 929	636 652	DIAND	4.79	32.8		200.0	n.d.	0.48		2.24
118	18	94-03-14	NWT LAB Access Rd.	6 928 031	635 237	DIAND	8.35	23.4	15.0	200.0	n.d.	0.55	0.25	2.24
119	18	94-03-14	NWT LAB Access Rd.	6 928 031	635 237	Norwest		34.4				0.82	0.25	2.24
120	19	94-03-14	At Hwy Junction 3 & 4	6 929 300	635 304	DIAND	7.09	89.5	21.0	100.0	2.9	1.04	0.36	1.12
121	20	94-03-14	City of YK Landfill Access Rd.	6 929 793	635 352	DIAND	6.06	67.8	30.0	200.0	n.d.	0.89	0.05	2.24
122	21	94-03-14	W Side of Hwy S of Giant Property	6 930 893	635 797	DIAND	6.66	262.0	62.0	200.0		3.44	0.99	2.24
123	22	94-03-14	W Side of Hwy Across From Propane Tanks	6 931 407	635 682	DIAND	6.93	320.0	88.0	200.0	n.d.	3.73	1.31	2.24
124	23	94-03-14	W Side of Hwy Across from Giant Main Gate	6 932 275	635 803	DIAND	7.49	672.0	247.0	200.0	n.d.	11.76	4.55	2.24
125	7	94-03-14	W Side of Hwy Adjacent to Giant Roaster Stack	6 932 926	635 984	Norwest		4 675.0	385.0	8 000.0		43.64	6.16	89.67
126	7	94-03-14	W Side of Hwy Adjacent to Giant Roaster Stack	6 932 926	635 984	DIAND	7.59	2 240.0			n.d.	45.74	6.16	89.67
127	24	94-03-14	W Side of Hwy at Vee Lk Access	6 933 867	635 989	DIAND	6.94	313.0	24.0	200.0	n.d.	3.20	0.35	2.24
128	25	94-03-14	N Side of Hwy 4	6 935 108	636 804	DIAND	7.13	29.4	22.0	200.0	n.d.	0.39	0.39	2.24
129	26	94-03-14	N Side of Hwy 4	6 934 925	636 993	DIAND	6.77	30.8	13.0	1 000.0	n.d.	0.40	0.21	11.21
130	51	94-03-14	S Side of Hwy 4 W of YK Bridge	6 933 925	637 817	DIAND	7.09	60.4	3.0	70.0	n.d.	0.62	0.54	0.78
131	27	94-03-14	N Side of Hwy 4 W of Dettah Turnoff	6 933 814	638 742	DIAND	7.93	43.7	5.0	100.0	n.d.	0.51	0.09	1.12
132	28	94-03-14	N Side of Hwy 4 at Dettah Turnoff	6 933 391	639 781	DIAND	7.68	32.3	2.0	300.0	n.d.	0.47	0.04	3.36
133	33	94-03-14	W Side of Dettah Access Rd N of Dettah	6 923 085	639 118	DIAND	7.45	21.0	7.0	70.0	n.d.	0.21	0.11	0.78
201	32	94-03-15	Back Bay W of Ndilo	6 929 843	636 949	DIAND	5.52	80.6	41.0	100.0	n.d.	1.65	0.41	1.12
202	43	94-03-15	Back Bay NW of N Point of Ndilo	6 931 076	637 260	Norwest		308.0	64.0	400.0		6.56	0.64	4.48
203	43	94-03-15	Back Bay N of N Point of Ndilo	6 931 076	637 260	DIAND	5.60	198.3			n.d.	2.89	0.64	4.48
204	42	94-03-15	Back Bay Point Near Giant Town Site	6 931 590	636 322	DIAND	6.36	181.0	120.0	400.0	n.d.	3.70	1.20	4.48
205	41	94-03-15	Back Bay E of Giant Roaster			Norwest		776.0	900.0	1 000.0		11.77	9.00	11.21
206	41	94-03-15	Back Bay E of Giant Roaster			DIAND	7.24	615.0			6.9	7.18	9.00	11.21
207	41	94-03-15	Back Bay E of Giant Roaster			DIAND	6.65	203.0			n.d.	2.37	9.00	11.21
208	44	94-03-15	Back Bay NE of N Point of Ndilo	6 930 678	637 449	DIAND	5.26	32.3	125.0	700.0	n.d.	0.28	1.25	7.85
209	44	94-03-15	Back Bay NE of N Point of Ndilo	6 930 931	637 738	DIAND	5.35	162.0			n.d.	1.42	1.25	7.85
210	44	94-03-15	Back Bay N of N Point of Ndilo	6 931 225	637 601	DIAND	5.51	320.0			n.d.	7.47	1.25	7.85
211	44	94-03-15	Back Bay NW of N Point of Ndilo	6 931 475	637 309	DIAND	5.55	82.1			n.d.	0.96	1.25	7.85
212	37	94-03-15	Bay on S Side of Jolliffe Island	6 928 487	637 059	Norwest		41.4	212.0	100.0		0.89	0.29	1.12
213	37	94-03-15	Bay on S Side of Jolliffe Island	6 928 487	637 059	DIAND	5.11	25.4			n.d.	0.37	0.29	1.12
214	36	94-03-15	Yellowknife Bay S of Jolliffe Island	6 928 186	636 902	DIAND	5.45	439.0	20.0	100.0	n.d.	5.12	0.20	1.12
215	35	94-03-15	Yellowknife Bay N of Mosher Island	6 927 102	637 129	DIAND	5.07	16.5	21.0	300.0	n.d.	0.24	0.21	3.36
216	34	94-03-15	Yellowknife Bay Shore at Negus Point	6 926 272	636 751	DIAND	6.20	37.2	4.0	80.0	n.d.	0.43	0.06	0.90
301	3	94-03-16	SW End of Baker lake	6 932 486	631 951	DIAND	5.43	202.0		700.0	n.d.	2.95		7.85
302	1	94-03-16	W of Baker Lake, N of Long Lake	6 931 751	631 808	DIAND	5.04	90.5		400.0	n.d.	1.19		4.48
303	4	94-03-16	East Shore of Baker Lake	6 933 051	633 287	DIAND	5.01	200.0		600.0	n.d.	2.33		6.73
304	5	94-03-16	W Shore of Lake E of Baker lake	6 933 123	634 040	DIAND	5.72	623.0		600.0	n.d.	14.54		6.73
305	6	94-03-16	Approx. 600 m W of Giant Roaster	6 932 883	634 790	DIAND	5.59	443.0	150.0	800.0	n.d.	12.28	2.88	8.97
306	6	94-03-16	Approx. 600 m W of Giant Roaster	6 932 883	634 790	Norwest		308.0				8.90	2.88	8.97
Geometric Mean							6.17	98.9			3.7	1.37		

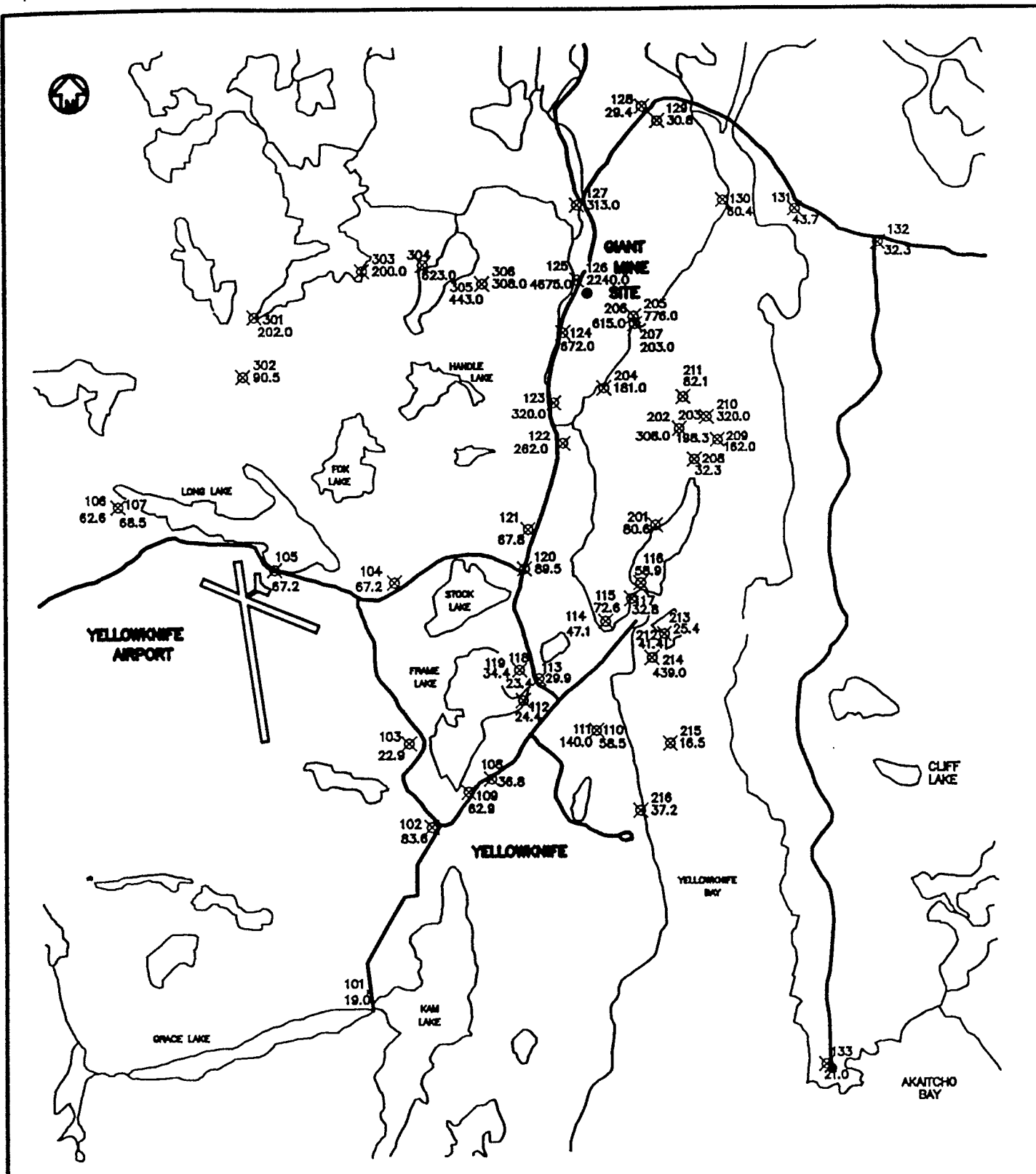
Note: UTM coordinates provided measured by handheld single receiver GPS unit.

Accuracy of instrument quoted by manufacturer as +/- 12 metres horizontally.

SAEL Sites represent nearest sampling site from 1986 Snow Core Study, Stanley Associates Engineering Ltd.

For graphic representation of locations, see Figure 1 of this report.

n.d. - below detection limits



DRAWING TITLE

**ARSENIC CONCENTRATION LEVELS ( $\mu\text{G/L}$ )**

JOB TITLE

**YELLOWKNIFE SNOW SAMPLING**

JOB NUMBER

94-0260

**FERGUSON, SIMEK, CLARK**  
CONSULTING ENGINEERS & ARCHITECTS

DESIGNED BY

KH

DRAWN BY

PW

CHECKED BY

SCALE

NTS

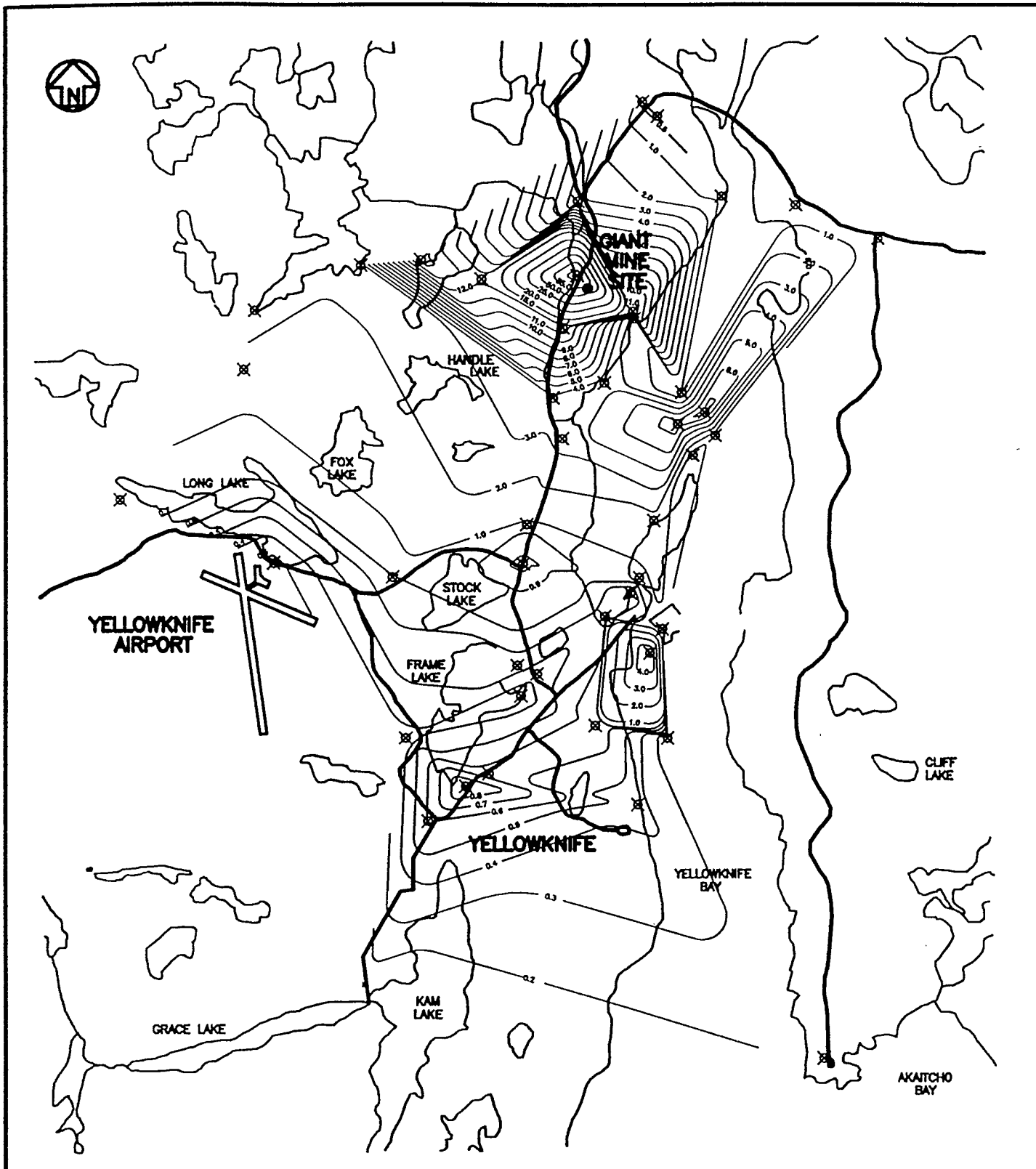
DATE

30 MAY 1994

DRAWING NO

Figure 2

P.O. BOX 1777 YELLOWKNIFE  
N.W.T., CANADA X1A2P4



DRAWING TITLE

**ARSENIC DEPOSITION ISOPLETHS ( $\text{kg}/\text{km}^2/\text{mo}$ )**

JOB TITLE

**YELLOWKNIFE SNOW SAMPLING**

JOB NUMBER

94-0260

**FERGUSON, SIMEK, CLARK**  
CONSULTING ENGINEERS & ARCHITECTS

DESIGNED BY

JC

SCALE

NTS

DRAWN BY

PW

DATE

15 JUNE, 1994

CHECKED BY

DRAWING NO

Figure 3

P.O. BOX 1777 YELLOWKNIFE  
N.W.T., CANADA X1A2P4

## 7.0 Conclusions

### 7.1 Comments

The discrepancies between the 1986 study and the 1994 study showing increased concentrations over earlier studies may be a real phenomenon or sample laboratory handling techniques. It was noted that the samples were melted and then shipped as water to the laboratory in the 1986 study.

We discussed the handling procedures with the laboratories and noted in the 1994 study that the samples were melted in the laboratory and shaken prior to measurement to maximize the dispersion of the arsenic particles in the sample prior to measurement. It could not be confirmed at this time whether the bags were shaken prior to pouring to sample bottles being sent to the laboratory for the 1986 study. If this was not the case, this would account for lower values due to precipitated arsenic left in the bags.

Care must be taken with sampling techniques and analytical design to get consistent results between studies.

### 7.2 Arsenic

This study is primarily a comparative program relating current data to two past studies carried out specifically for the purpose of measuring arsenic contamination by snow sampling programs.

The 1986 study concluded that a marked improvement in the arsenic deposition rates had occurred between 1975 and 1986.

The data analyzed in the current program revealed higher arsenic values in snow cores than were found in the 1986 study. The geometric mean of the deposition rate for the current study was  $1.37 \text{ kg/km}^2\cdot\text{mo}$  as compared with the 1986 study value of  $0.40 \text{ kg/km}^2\cdot\text{mo}$  and the 1975 value of  $1.9 \text{ kg/km}^2\cdot\text{mo}$ .

The concentrations of arsenic in 34 of the 55 or 62% of the samples collected in the current program exceeded the Maximum Acceptable Concentration of 50  $\mu\text{g/L}$  as defined by the CDWS. As noted previously, the current Intermediate MAC value is 25  $\mu\text{g/L}$ . Only 4 of the 55 samples collected were below the current IMAC value.

Of these samples exceeding the earlier allowable level, 19 measured one order of magnitude greater and two measured two orders of magnitude greater than the allowable limit. The geometric mean of the total arsenic concentration for the 1994 sample group was 98.9  $\mu\text{g/L}$  compared with the 1986 result of 28  $\mu\text{g/L}$  and the 1975 result of 170  $\mu\text{g/L}$ . The geometric mean of the concentrations of arsenic in this study represent an increase of 253% over the most recent snow sampling program.

The data indicates that the locations of greatest arsenic contamination are consistently in the region of the Royal Oak Mines Giant Mine Property throughout the three studies.

The general trends of the deposition of arsenic are similar in all three studies. The deposition patterns are shown in Figures 4(a - c).

### 7.3 pH

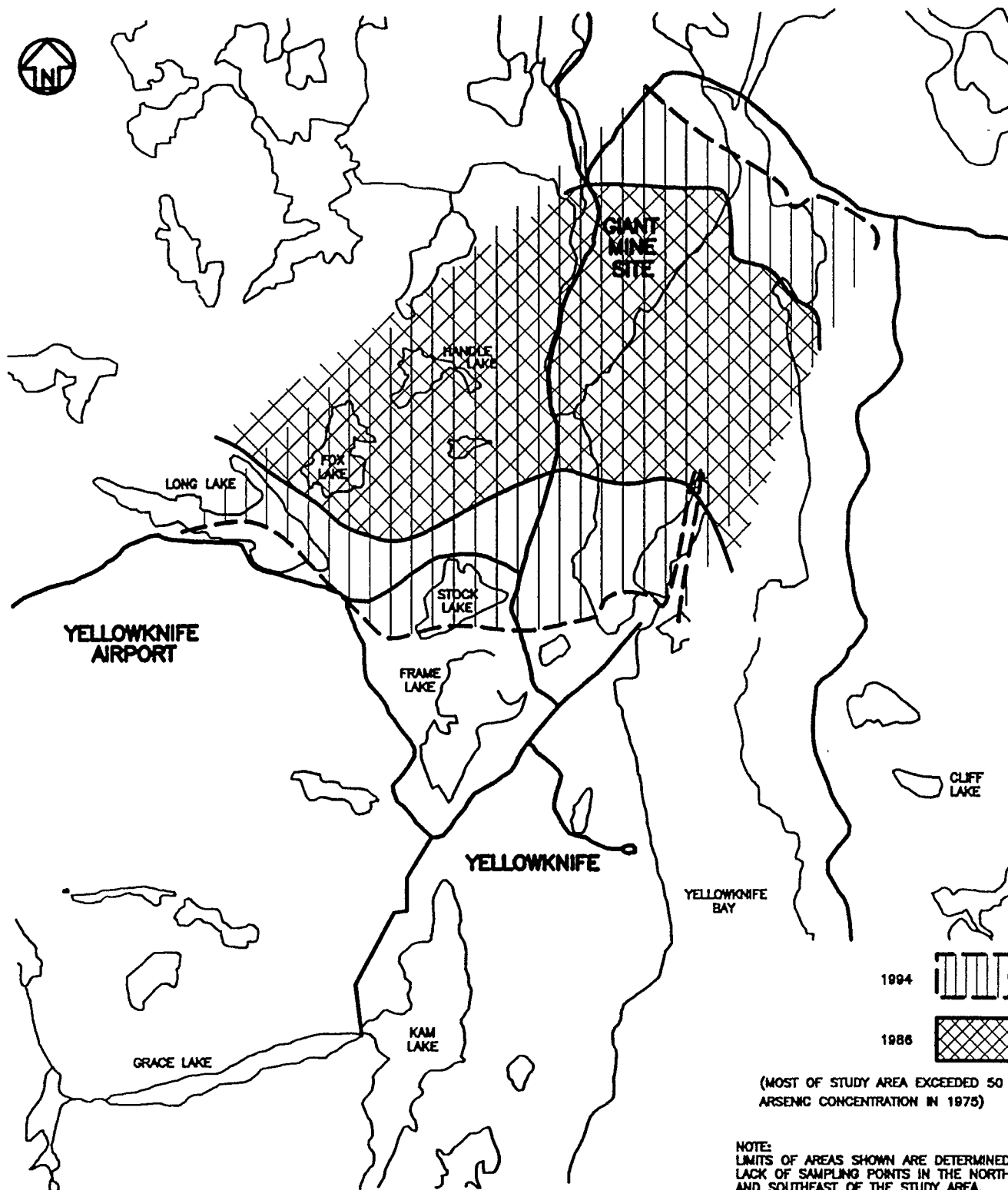
pH levels recorded in the 1994 program were generally less than the recommended level for drinking water. The level recommended by the CDWS is between 6.5 and 8.5. The geometric mean pH level measured in the 1994 sample group was 6.17 with values varying between 4.78 and 8.35.

The pH change may have to be compared to precipitation or snow melt values for the Yellowknife area rather than to the CDWS. pH of snow generally ranges from 5.5 - 6.5.



#### 7.4 Sulphate

Increased sulphate concentration would be an indication of sulphur compound emissions. In order to interpolate the results one would have to account for all sulphur sources in the Study Area. As concluded from the 1986 study, the sulphate levels were no higher in the vicinity of Giant operations as compared to the Yellowknife area. In the 1994 study, conclusions can not be given because of lack of data from using a Laboratory method with a detection limit of 3 mg/L.



1994



1986



(MOST OF STUDY AREA EXCEEDED 50 µg/L  
ARSENIC CONCENTRATION IN 1975)

NOTE:  
LIMITS OF AREAS SHOWN ARE DETERMINED BY  
LACK OF SAMPLING POINTS IN THE NORTHWEST  
AND SOUTHEAST OF THE STUDY AREA.

DRAWING TITLE

**AREA EXCEEDING 50 µg/L ARSENIC CONCENTRATION**

JOB TITLE

**YELLOWKNIFE SNOW SAMPLING**

JOB NUMBER

94-0260

FERGUSON, SIMEK, CLARK  
CONSULTING ENGINEERS & ARCHITECTS

DESIGNED BY JC

SCALE NTS

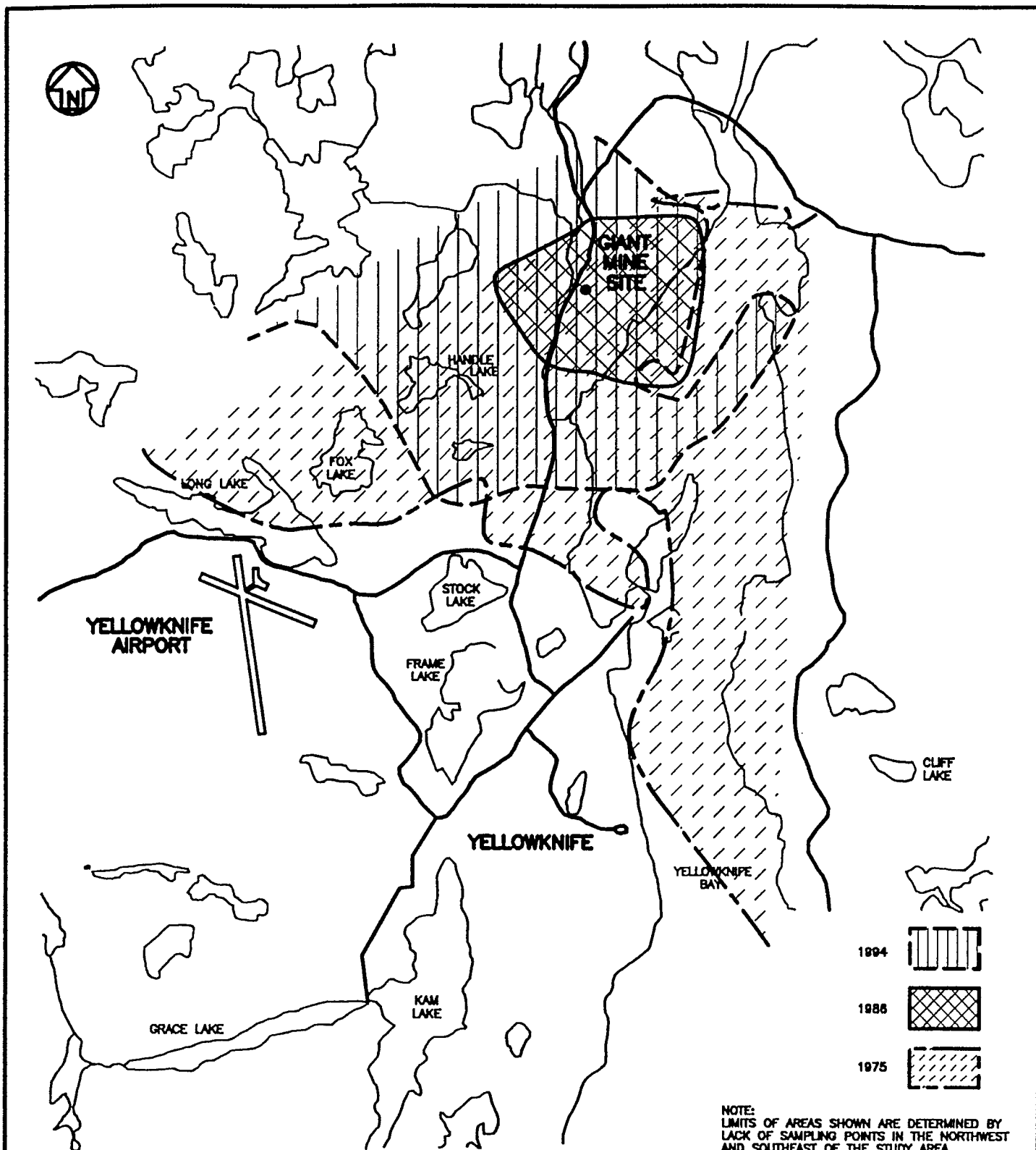
DRAWN BY JC

DATE 17 JUNE, 1994

CHECKED BY

DRAWING NO Figure 4a

P.O. BOX 1777 YELLOWKNIFE  
N.W.T., CANADA X1A2P4



DRAWING TITLE

**AREA EXCEEDING  $150\mu\text{g/L}$  ARSENIC CONCENTRATION**

JOB TITLE

**YELLOWKNIFE SNOW SAMPLING**

JOB NUMBER

**94-0260**

**FERGUSON, SIMEK, CLARK**  
CONSULTING ENGINEERS & ARCHITECTS

DESIGNED BY JC

SCALE

**NTS**

DRAWN BY JC

DATE

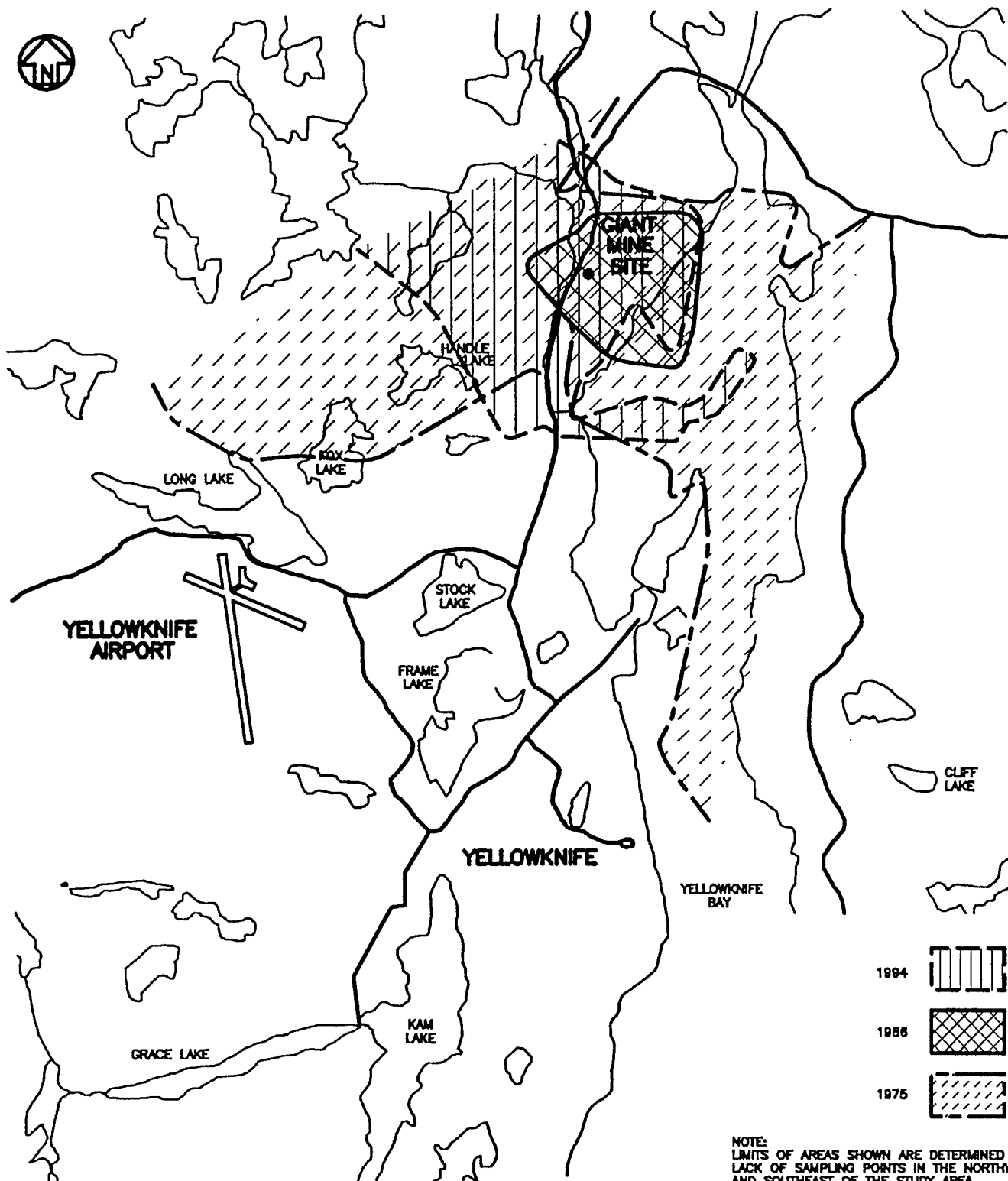
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**Figure 4b**

P.O. BOX 1777 YELLOWKNIFE  
N.W.T., CANADA X1A2P4



NOTE:  
LIMITS OF AREAS SHOWN ARE DETERMINED BY  
LACK OF SAMPLING POINTS IN THE NORTHWEST  
AND SOUTHEAST OF THE STUDY AREA.

DRAWING TITLE

**AREA EXCEEDING 250µg/L ARSENIC CONCENTRATION**

JOB TITLE

**YELLOWKNIFE SNOW SAMPLING**

JOB NUMBER

94-0260

**FERGUSON, SIMEK, CLARK**  
CONSULTING ENGINEERS & ARCHITECTS

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SCALE  
NTS

DATE  
17 JUNE, 1994

DRAWING NO  
Figure 4c

P.O. BOX 1777 YELLOWKNIFE  
N.W.T., CANADA X1A2P4

## 8.0 Recommendations

1. *Ion chromatography or techniques of similar sensitivity should be used for analysis of sulphur compounds if these compounds are of concern at the time of future studies (APHA 4110B Ion Chromatography – detection limit 0.1mg/L).*
2. *The study area should be extended to the northwest and southeast if arsenic concentrations in snow are to be monitored and compared to Canadian Drinking Water Standards. Presently arsenic concentrations in snow are above CDWS levels at the northwest and southeast edges of the study area.*
3. *It would be useful to develop or adopt a standard methodology to be used in future. A standard methodology would allow comparisons between studies in the area of sample handling in the field, sample transfer to the laboratory, sample preparation and sub-sampling in the laboratory. An increased number of number of controls and replicates should be incorporated.*
4. *This study is focused on snow deposition of arsenic. Studies of soil concentration in the areas of highest deposition would be useful to look at the cumulative effect on the environment. This would also require background samples to be taken in areas unaffected by the deposition in the Yellowknife area.*

## 9.0 References

1. *"An Investigation of Atmospheric Emissions from the Royal Oak Giant Yellowknife Mine."* Environmental Protection Division Department of Renewable Resources Government of the Northwest Territories, Yellowknife, NT. June 1993.
2. *"Report Prepared for Government of the Northwest Territories Department of Renewable Resources, Sampling and Analysis of Snow Cores in the Yellowknife Area, April 1986."* Stanley Associates Engineering Ltd.
3. *"Chemical Characteristics of Snow in the Yellowknife Area, NWT - 1975."* Environment Canada, Environmental Protection Service, July, 1977.
4. *"The Arsenic Papers."* M. A. Rychlo, 1977. Published by Highway Book Shop, Cobalt, On. ( Supplemental general information source)

# Air Quality Monitoring in Yellowknife

