Environment Canada
Environmental Protection Service

Environnement Canada
Service de la protection de l'environnement

Chemical Characteristics of Snow in the Yellowknife Area, N.W.T. - 1975

Surveillance
Report EPS-5-NW-77-7
Northwest Region
July, 1977

ENVIRONMENTAL PROTECTION SERVICE REPORT SERIES

Surveillance Reports present the results of monitoring programs carried out by or for the Environmental Protection Service. Some of these reports will be published on a regular basis.

Other categories in the EPS series include such groups as Regulations, Codes and Protocols; Policy and Planning; Economic and Technical Review; Technology Development; Training Manuals; Briefs and Submissions to Public Inquiries; and Environmental Impact and Assessment.

Inquiries pertaining to Environmental Protection Service Reports should be directed to the Environmental Protection Service, Fisheries and Environment Canada, #901, 10025 Jasper Avenue, Edmonton, Alberta T5J 2X9.

CHEMICAL CHARACTERISTICS OF SNOW IN THE YELLOWKNIFE AREA, N.W.T.
1975

by

Asit K. Hazra

Roy Prokopuk

and

M.J. Hardin

Northwest Region

Environmental Protection Service

Environment Canada

July 1977

ABSTRACT

As part of the Yellowknife Environmental Survey the Environmental Protection Service conducted an investigation of the concentration and distribution of contaminating substances in snow during the winter of 1975. The prime objectives and results of the survey are presented. Both scoop and core snow samples were collected. The data indicated that the quality of surface layers of snow can be significantly different from that of the total accumulated snowfall. Analytical techniques consisted of atomic absorption spectroscopy and Vasak and Sedivec colorimetric methods. The results indicate that the snow in the Yellowknife area does not conform to specifications for pH, arsenic, lead, iron and manganese, under the Canadian Drinking Water Standards, 1968. Hence, the recommendation is made that the public be informed of the potential hazard and dissuaded from using melted snow as a source of potable water in the Yellowknife area.

RESUME

Dans le cadre de l'enquête environnementale menée à Yellowknife par le Service de la protection de l'environnement, les techniciens ont observé la concentration et la distribution des contaminants contenus dans la neige pendant l'hiver de 1975. Le document présente les principaux objectifs et résultats de l'enquête. Les prélèvements d'échantillons se sont effectués à la pelle et par carottage. Les données accumulées ont indiqué que les caractéristiques de la neige superficielle peuvent différer de façon notable de celles de l'accumulation totale. Pour les analyses techniques, les chercheurs ont eu recours à la spectroscopie d'absorption atomique ainsi qu'aux méthodes colorimétriques Vasak et Sedivec. Les résultats montrent que la neige de la région de Yellowknife ne se conforme pas aux Normes et objectifs pour l'eau potable au Canada (1968) en ce qui concerne le pH et le niveau d'arsenic, de plomb, de fer et de manganèse. On recommande donc, dans le but d'enrayer cette pratique, d'informer le public des dangers éventuels d'avoir recours à la neige fondue comme source d'eau potable dans la région de Yellowknife.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CONCLUSIONS AND RECOMENDATIONS

CONCLUSIONS

1. The concentrations of arsenic in samples of snow collected during the months of February, March and April 1975 in the vicinity of Yellowknife almost invariably exceeded the maximum permissible level established by the Canadian Drinking Water Standards and Objectives.
2. The highest concentrations of arsenic were detected in the surface layers of snow during this survey, and this is attributed to short term meteorological phenomena.
3. The concentrations of lead, iron and manganese in snow in this area occasionally exceeded the levels specified by the Standards.
4. The pH of snow both in the vicinity of Yellowknife and in more distant areas did not generally fall within the range specified by the Standards.
5. The mean concentration of arsenic in melted scoop snow samples was 0.59 mg/l, whereas in melted core snow samples the mean was 0.17 mg/l.
6. The estimated mean deposition rate of arsenic in the Yellowknife area was 0.0053 tons of arsenic per square mile per month.

RECOMMENDATIONS

1. An intense effort should be made to inform the public of elevated levels of arsenic in snow in the Yellowknife area, and to strongly discourage the use of contaminated snow as a source of potable water.
2. In view of the significant quantities of arsenic present in the snow of the Yellowknife area it is recommended that further studies be conducted to measure the concentration of arsenic in spring runoff, and determine the final fate of the arsenic. An additional investigation to document the consequences of contamination by arsenic on the aquatic and terrestrial ecosystems should also be undertaken.
3. Upon completion of the recommended studies, the rates of release of arsenic should be decreased to levels which will adequately mitigate undesirable environmental effects.

1 INTRODUCTION

The use of melted snow as a source of potable water in communities in Northern Canada is a common practice. In the area of Yellowknife, however, the use of snow for this purpose has been suspected for some time to be ill-advised. This is due to the emission of considerable quantities of arsenic and other toxicants into the atmosphere. This suspicion was strengthened by a preliminary analysis of snow collected on Yellowknife Bay in 1974 (1), where a concentration of 0.47 mg/l was detected in a sample taken approximately two miles southeast of the roaster stack at Giant Yellowknife Mines. Previous measurements by O'Toole had already indicated the contamination of snow in the Yellowknife area by arsenic (2).

An intensive program for the sampling and analysis of snow in this area was therefore undertaken by the Environmental Protection Service in March and April of 1975, as part of the Yellowknife Environmental Survey (3).

The prime objectives of the snow survey were two fold: firstly to quantify the concentration of arsenic in melted snow water and secondly to assess the deposition rate of arsenic during the winter by measuring the cumulative amount of arsenic entrapped in the snow.

The two major sources of arsenic in the Yellowknife area are the operations of Giant Yellowknife Mines Limited (Giant Mine) and Cominco Limited (Con Mine). Giant Mine's roaster stack is the most significant source of arsenic emissions. Con Mine, having discontinued roasting operations since 1970, is presently a source of fugitive arsenic emissions.

2 SAMPLING PROCEDURES AND LOCATION OF SITES

2.1 Scoop Samples

Two different techniques were utilized for the collection of snow samples. The first technique consisted of scooping sufficient snow from the top six or seven inches by means of a plastic bowl to form a composite sample. Initially 12 such samples were collected in plastic bags on February 17, 1975. Subsequently an additional 120 such samples including six control samples were collected during the last week of March and the first week of April 1975. The six control samples were taken at distances of approximately 30, 60 and 90 miles northeast and the other three were collected at 10, 20 and 30 miles to the west of the city. The locations of the sampling sites have been shown in Figures 1 and 2.

2.2 Core Samples

The second technique consisted of using a 3 inch diameter corer to obtain core samples through the entire depth of snow. Composite samples containing approximately 9 to 15 core samples were taken at each location to ensure an adequate volume for analysis. A total of 52 such samples were collected in plastic bags between March 25, 1975 and April 15, 1975. The locations of the sampling sites have been shown in Figure 3.

3 SAMPLE ANALYSIS

3.1 Scoop Samples

Collected samples were allowed to melt at room temperature in Yellowknife, and the pH of the melted snow samples was determined using a meter. The samples were then transferred into plastic bottles for shipment to the Environment Canada Water Quality Laboratory in Calgary. No algicide or preservative was added to the samples. On receipt at the laboratory the conductivity of the samples was measured using a conductivity meter. Next, total arsenic and total antimony determinations were conducted utilizing the atomic absorption spectroscopy technique.

3.2 Core Samples

The core snow samples, on receipt at the EPS Regional Laboratory in Edmonton were allowed to melt at room temperature. The pH of the melted snow samples was determined using a meter. Sulphate analyses were conducted utilizing the turbidimetric method (4). In preparation for the metals analyses, aliquots of these composite samples were preserved with 1 ml of concentrated nitric acid per liter of sample. These aliquots were subsequently analysed by the EPS Regional Laboratory, for arsenic

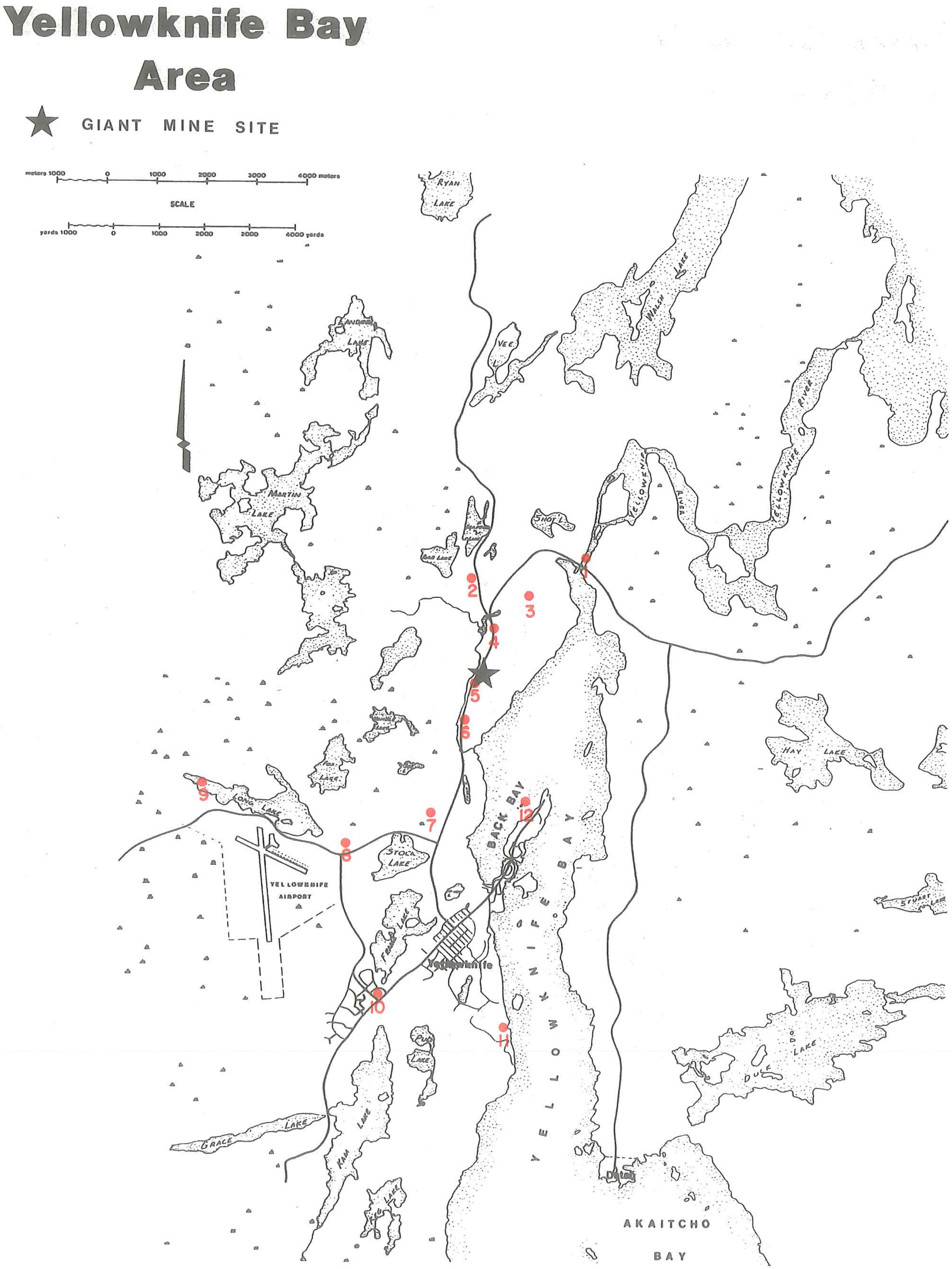


FIGURE I. LOCATION OF SCOOP SNOW SAMPLE SITES – FEBRUARY 1975

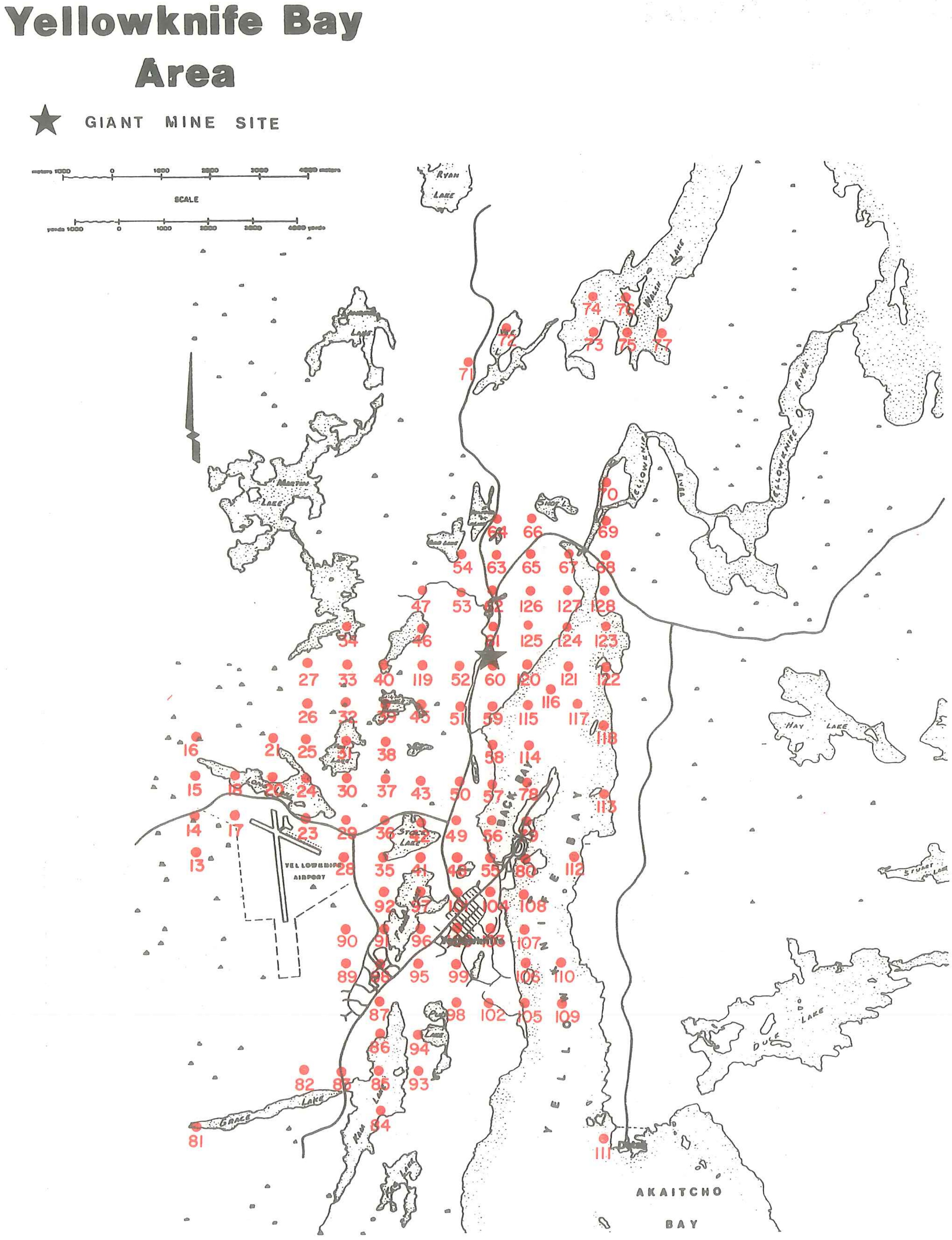


FIGURE 2. LOCATION OF SCOOP SNOW SAMPLE SITES – MARCH/APRIL 1975

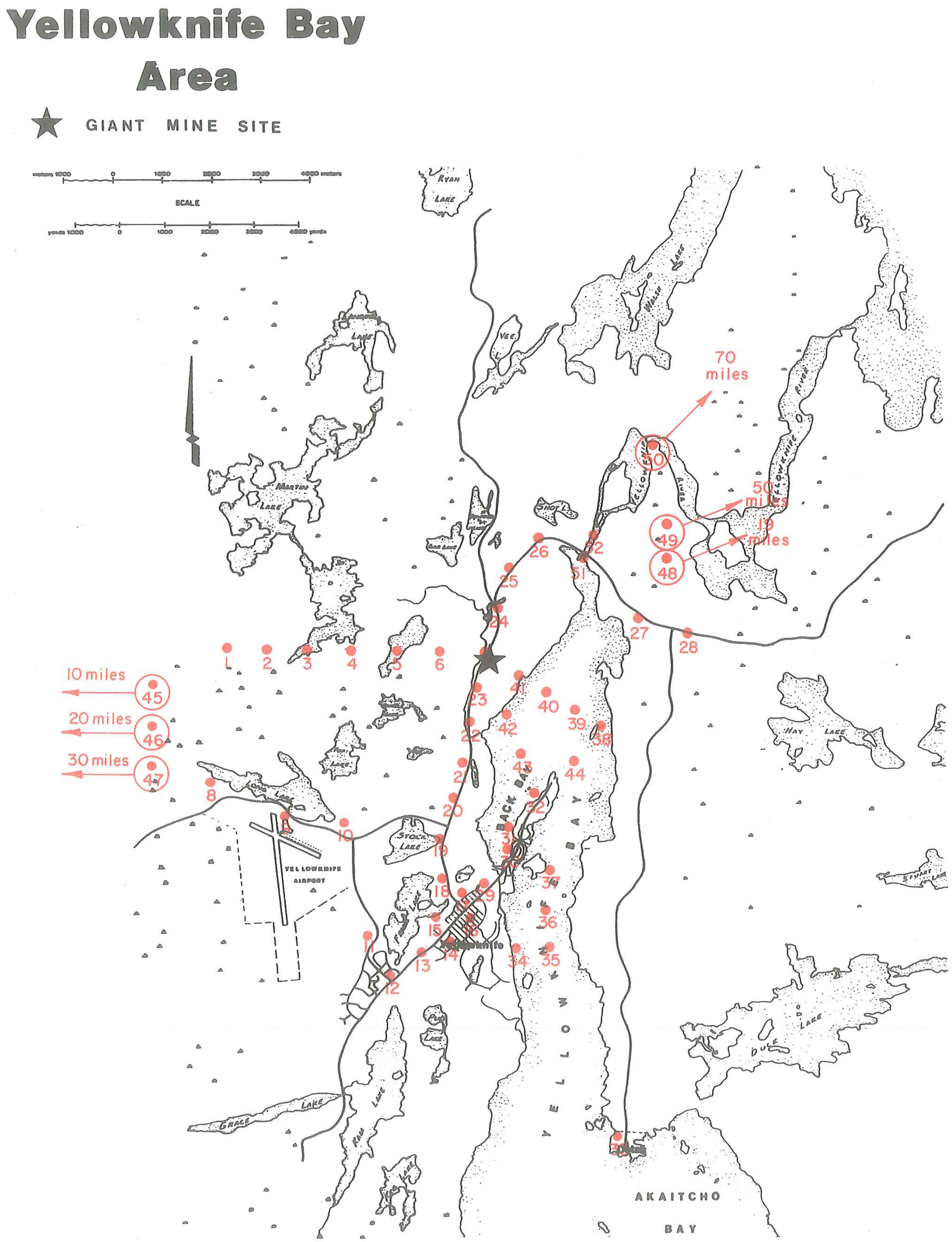


FIGURE 3. LOCATION OF CORE SNOW SAMPLE SITES - MARCH/APRIL 1975

utilizing the Vasak and Sedivec (pyridine) technique and for antimony, beryllium, cadmium, copper, iron, lead, manganese, nickel and zinc utilizing atomic absorption spectroscopy (5). Additional aliquots of each of the composite samples were preserved with 4 ml of concentrated sulfuric acid and sent to the Environment Canada Water Quality Laboratory in Calgary for mercury analysis utilizing the atomic absorption spectroscopy technique (6).

4 RESULTS AND DISCUSSION

4.1 Scoop Samples

The concentrations of arsenic at the twelve stations sampled in February are presented in Figure 4, and those measured in March-April are shown in Figure 5. These data are summarized in Table 1, together with the measurement of specific conductance and pH.

The limited number of samples collected in February indicated a large range in values as well as the highest concentrations recorded during the study. When the number of samples was increased approximately ten-fold for the March-April collection, the variability in the concentration of arsenic was decreased, and the maximum values detected were also lower. Minimum values were similar, however, in both cases.

The data clearly indicate that extensive contamination of snow by arsenic in the Yellowknife area existed at the time when these samples were collected (Table 2). The concentrations of arsenic in all but two of the 126 samples collected exceeded the maximum permissible concentration of 0.05 mg/l specified by the Canadian Drinking Water Standards and Objectives (98%). Moreover, 72 of these samples (57%) contained arsenic at concentrations at least an order of magnitude greater than the limit specified by the Standards.

An attempt was made to correlate these results with wind rose information presented in Appendix I. As expected, no regular pattern of areal distribution of arsenic in snow was observed in these measurements. Maximum values were detected, however, in the area southwest of the roaster stack at Giant Yellowknife Mines Limited. Otherwise the distribution of arsenic appeared to be generally random. It is noteworthy,

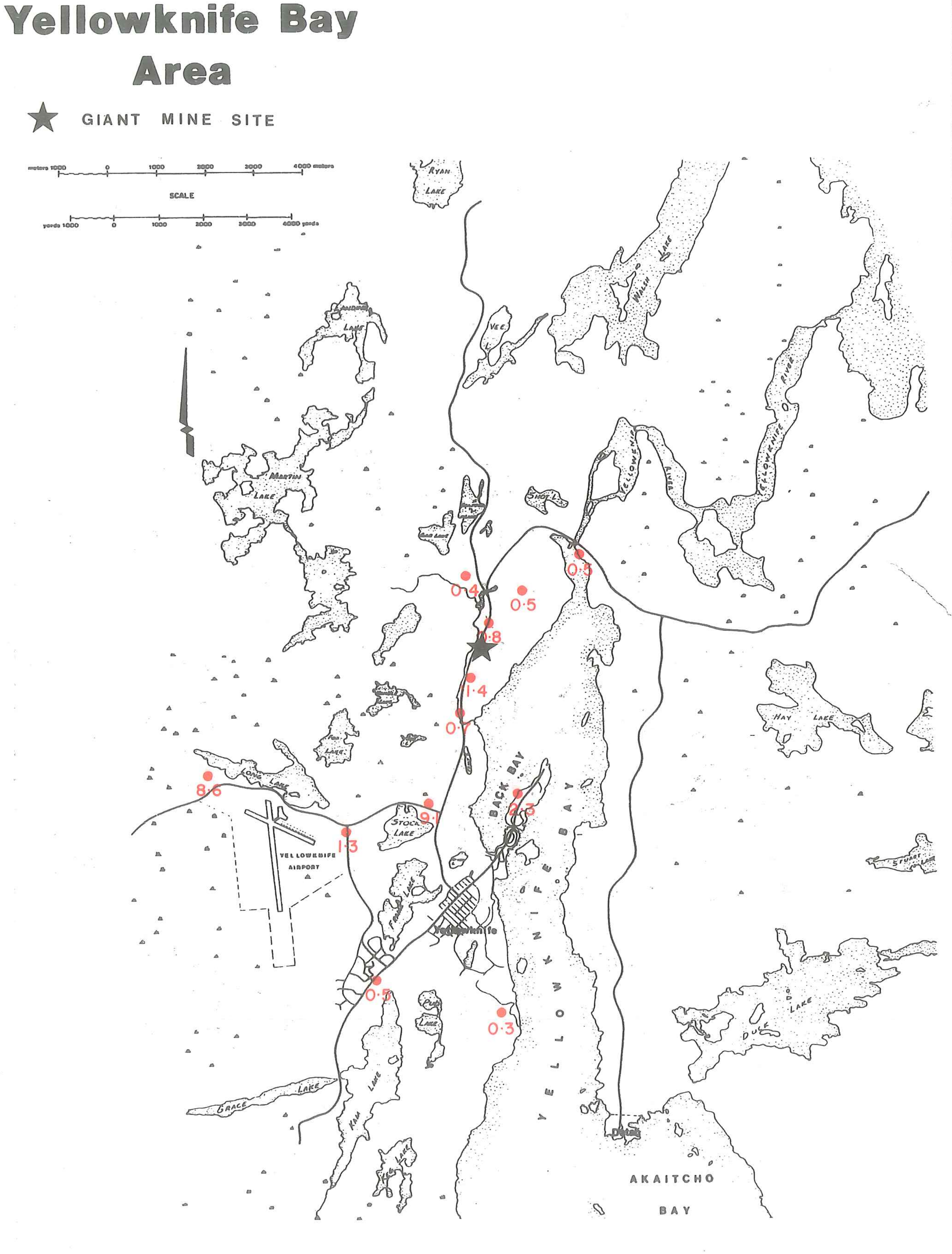


FIGURE 4. ARSENIC CONCENTRATIONS IN SCOOP SNOW SAMPLES FEBRUARY 1975

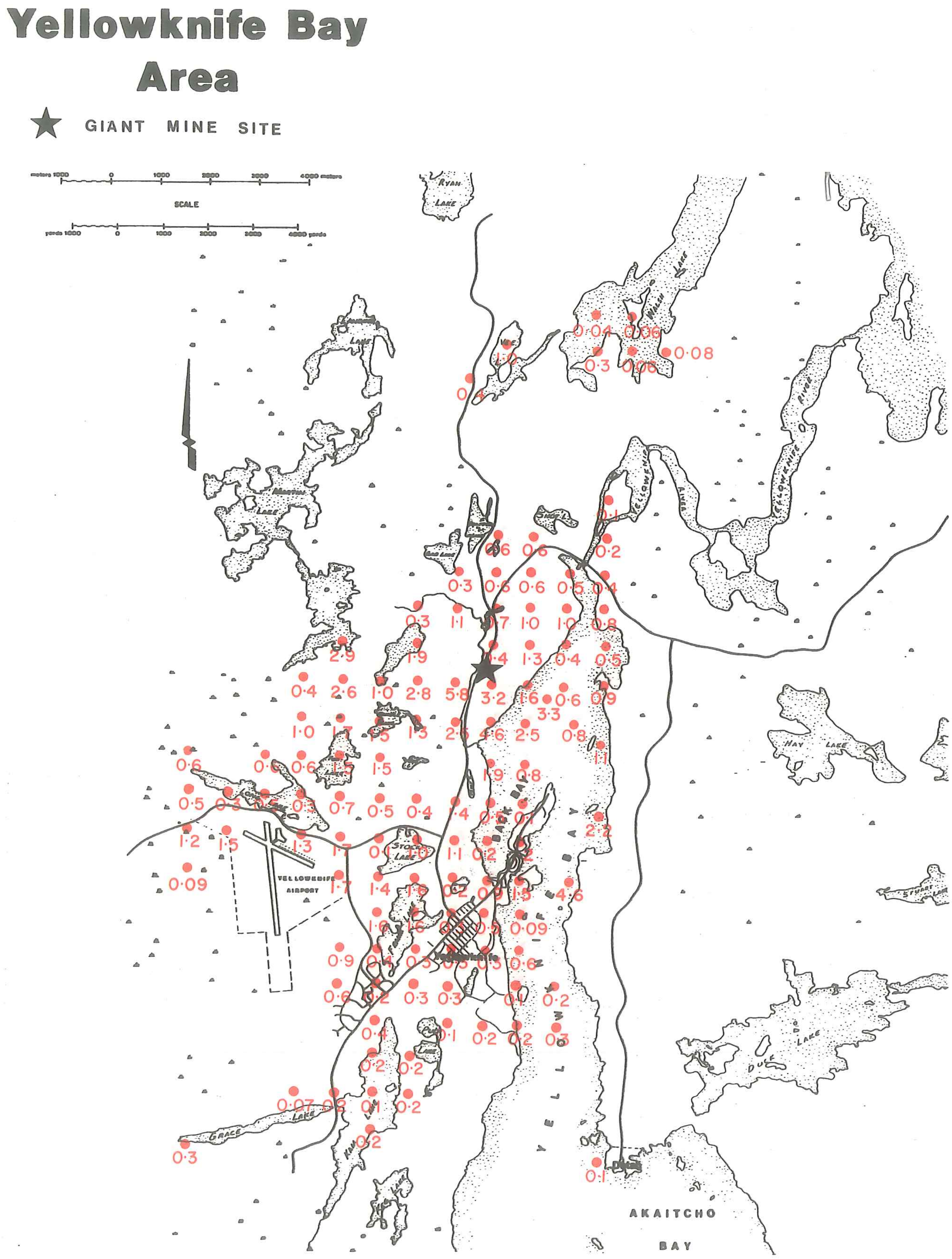


FIGURE 5. ARSENIC CONCENTRATIONS IN SCOOP SNOW SAMPLES MARCH/APRIL 1975

TABLE 1. SUMMARY OF RESULTS FOR SCOOP SNOW SAMPLES
Twelve samples were collected in February, and 114 in March-April

Survey	Parameter	Range of Results	Canadian Drinking Water Standards	Geometric Mean
February	Total Arsenic (mg/1)	0.03-11.4	<0.05 mg/1	1.06
	pH	3.40-6.70	6.5-8.3	4.30
	Specific Conductance (µmho/cm)	23.0-190	None	60.85
March-April	Total Arsenic (mg/1)	0.04-5.80	<0.05 mg/1	0.55
	pH	3.20-8.80	6.5-8.3	3.87
	Specific Conductance (µmho/cm)	4.30-337	None	17.05

TABLE 2. FREQUENCY DISTRIBUTION OF CONCENTRATIONS OF ARSENIC IN SCOOP SAMPLES COLLECTED IN FEBRUARY AND MARCH-APRIL. All concentrations are in mg/l. The maximum concentration specified by the Canadian Drinking Water Standards is 0.05 mg/l.

Range of Concentrations of Arsenic	Frequency Distribution	
	Number of Samples	Per Cent of Samples
<0.05	2	<1
0.05 - 0.25	26	21
0.25 - 0.50	26	21
0.5 or greater	72	57
Geometric Mean Concentration of Arsenic for 126 Samples		0.59 mg/l

however, that a number of values well above the maximum acceptable limit were detected on Vee Lake and Walsh Lake (Stations 71, 72, and 73) and at Stations 69 and 70 on the Yellowknife River. All of these locations lie within the watershed of the Yellowknife River upstream of the City's municipal intake.

Concentrations of arsenic were generally much lower at the "control" stations northeast of Yellowknife, but were somewhat higher at "control" locations to the west (Table 3). While recognizing the small number of samples it is interesting to note that an inverse relationship existed betweeen the concentration of arsenic and the distance of the control station from the Giant Mines stack.

The pH of most scoop samples (98%) was generally lower than the minimum acceptable value of 6.5 specified by the Drinking Water Standards, but the same was also true of the "control" samples. Hence no correlation between the pH of snow and industrial activities in the Yellowknife area may be drawn from this work.

Drinking water standards for specific conductance do not presently exist in Canada. However, the values measured were, in all but a few anomalous cases, very low (Tables 1 and 3).

Approximately sixty of the samples collected during the March-April survey were also analyzed for total antimony. The majority of these samples contained less than the detectable limit (0.006 mg/l), and the remainder, only very slightly more. Hence, the actual values have not been reported.

The results obtained from the scoop sampling program are indicative only of the chemical characteristics of the top layers of snow at the particular time of sampling. Such samples are probably representative of recent precipitation events and could be strongly influenced by very short term meteorological conditions prevailing during and in between these recent precipitation events. No attempt, therefore, can be made to infer the quality of the total snowpack from these results. It is important, however, to note that these layers of snow are the most likely to be utilized by humans or other animals. The data clearly indicated that meltwater of an unacceptable quality for potable use would be obtained during this time of the year.

TABLE 3. CHEMICAL PROPERTIES OF "CONTROL" SCOOP SAMPLES COLLECTED IN MARCH-APRIL IN AREAS DISTANT FROM YELLOWKNIFE.

Sampling Locations (Distance and Direction from Yellowknife)	Parameter		
	pH	Specific Conductance (μmho/cm)	Total Arsenic (mg/l)
30 Miles Northeast	3.7	128	0.033
60 Miles Northeast	4.4	30.3	0.020
90 Miles Northeast	3.7	105	0.0028
10 Miles West	3.5	176	0.32
20 Miles West	3.3	272	0.075
30 Miles West	4.8	156	0.061
Minimum	3.30	30.30	0.0028
Maximum	4.8	272	0.32
Geometric Mean	3.87	120.37	0.04

4.2 Core Samples

The accuracy of the analytical results for the core samples was checked as part of the quality assurance program, and the results are given in Table 4. Accuracy was generally satisfactory for determinations of heavy metals, although it was poorer for sulphate, arsenic and antimony. The accuracy tests on the analysis of mercury were inconclusive due to major analytical inconsistencies.

The concentrations of arsenic measured in core snow samples are given in Figure 6, and the results of these measurements are summarized in Table 5, together with the data for the other parameters which were determined. In addition, a frequency distribution of the concentrations of arsenic obtained in these samples is given in Table 6. An analysis of these data and a comparison with the specifications of the Canadian Drinking Water Standards (1968) indicates the following: the concentration of arsenic in 83% of these samples was greater than the maximum permissible level of 0.05 mg/l specified by the Standards, and 15% of the values were at least an order of magnitude greater than the limit. Most samples (90%) also did not fall within the range of pH specified by the Standards. Elevated concentrations of lead were noted in a number of instances, and 15% of the samples analyzed contained concentrations in excess of the value of 0.05 mg/l specified by the Standards. Values for iron were also high, such that 37% of the samples exceeded the maximum of 0.3 mg/l indicated by the Standards. A small number of samples (6%) also contained manganese in excess of the limit of 0.05 mg/l specified by the Standards. Concentrations of copper, cadmium, sulphate and zinc, however, did not exceed the levels specified by the Standards.

Core samples are representative of all deposition and precipitation events occuring since the first snow cover for the particular winter season. Isopleths of arsenic concentrations from these results have been presented in Figure 7. As expected, the isopleths correlate well with the wind rose information presented in Appendix I, since such samples are not strongly influenced by very short term meteorological conditions.

A frequency distribution of total arsenic deposition rates has been presented in Table 7. A geometric mean value of 0.0053 tons

TABLE 4. ACCURACY OF ANALYTICAL RESULTS FOR CORE SAMPLES

Parameter	Quantity of Preservative per liter of Sample	Time Limit for Analysis (in days)	Method of Analysis	Actual Time of Analysis (in days)	Reproducibility (±%)
pH	None	0.25	Hydrogen Ion Meter	<2	2
Arsenic	1 ml conc. Nitric Acid	180	Vasak/Sedivec Colorimetry	<30	15
Sulphate	None	7	Turbidimetric Method	<14	10
Antimony	1 ml conc. Nitric Acid	180	Atomic absorption spectroscopy	<45	20
Beryllium	"	180	"	"	5
Cadmium	"	180	"	"	5
Copper	"	180	"	"	5
Iron	"	180	"	"	3
Lead	"	180	"	"	6
Manganese	"	180	"	"	2
Mercury	4 ml conc. Sulfuric Acid	7	"	<7	Inconclusive
Nickel	1 ml conc. Nitric Acid	180	"	<45	5
Zinc	"	180	"	"	5

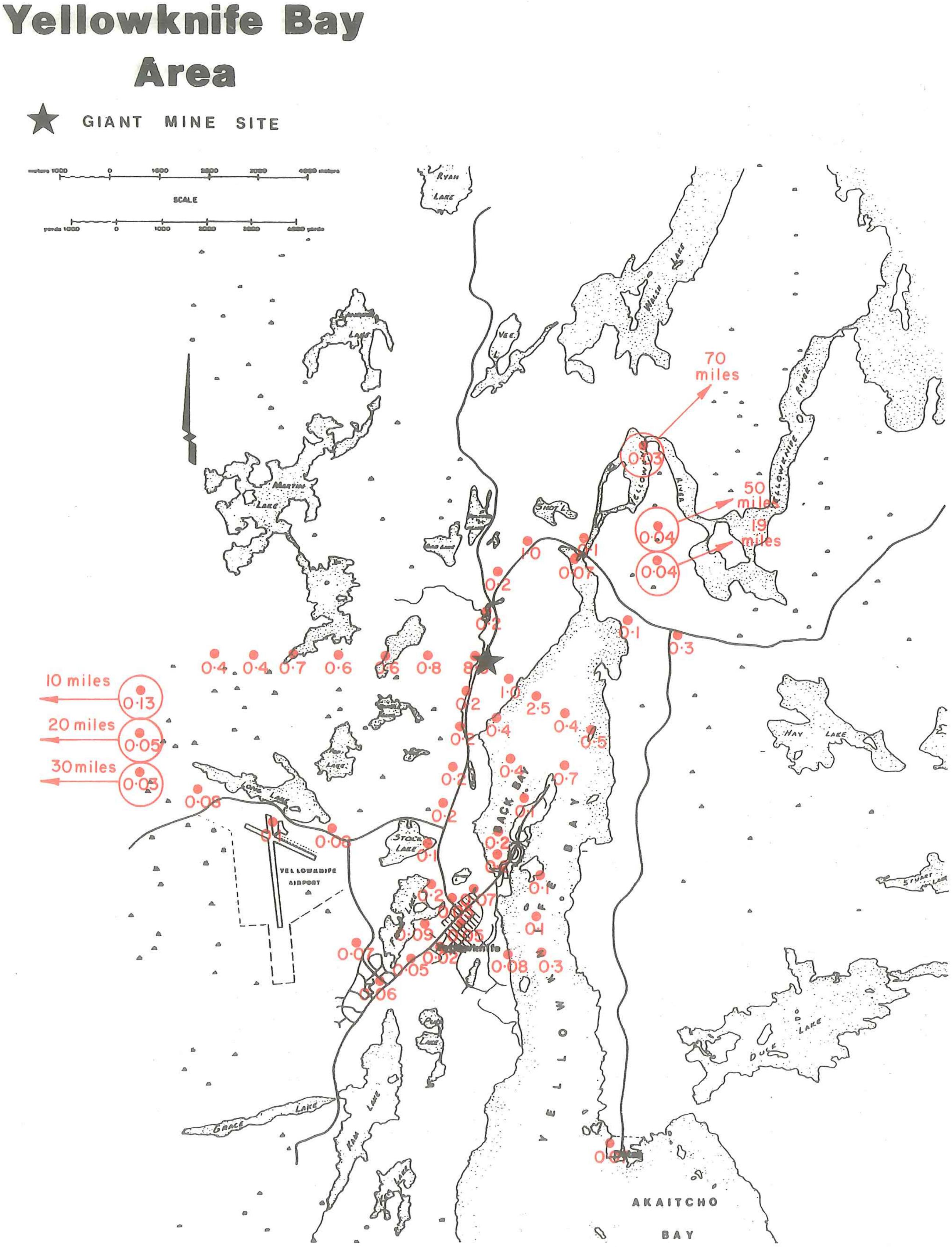


FIGURE 6. ARSENIC CONCENTRATIONS IN CORE SNOW SAMPLES MARCH/APRIL 1975

TABLE 5. SUMMARY OF RESULTS FOR CORE SNOW SAMPLES

Parameter	Sample Analysis Range	Reproducibility (±%)	Canadian Recommended Allowable Limit for Potable Water	Samples <u>Not</u> Within Recommended Canadian Allowable Limit		EPA (1973) Recommended Maximum Limit
				Number	%	
pH	2.7 - 7.7	2	6.5 - 8.3	47	90	5 - 9
Arsenic	0.02 - 8.8 μg/ml	15	<0.05 μg/ml	43	83	<0.10 μg/ml
Sulphate	<1 - 5 μg/ml	10	<500 μg/ml	0	0	<250 μg/ml
Antimony	<0.10 μg/ml	20	-	-	-	<0.2 μg/ml
Beryllium	<0.025 μg/ml	5	-	-	-	-
Cadmium	<0.014 μg/ml	5	<0.01 μg/ml	0	0	<0.01 μg/ml
Copper	<0.01 - 0.18 μg/ml	5	<1 μg/ml	0	0	<1 μg/ml
Iron	<0.02 - 0.8 μg/ml	3	<0.3 μg/ml	19	37	<0.3 μg/ml
Lead	<0.1 - 0.4 μg/ml	6	<0.05 μg/ml	8	15	<0.05 μg/ml
Manganese	<0.01 - 0.18 μg/ml	2	<0.05 μg/ml	3	6	<0.05 μg/ml
Mercury	<0.05 - 0.56 μg/ml	N.A.	<2 μg/ml	0	0	<2 μg/ml
Nickel	0.02 - 0.05 μg/ml	5	-	-	-	<0.1 μg/ml
Zinc	<0.003 - 0.123 μg/ml	5	<5 μg/ml	0	0	<5 μg/ml

TABLE 6. FREQUENCY DISTRIBUTION OF ARSENIC CONCENTRATIONS IN MELTED CORE SNOW SAMPLES

Range of Arsenic Concentrations (μg/ml)	Frequency distribution of Snow Samples Analyzed	
	Number of Samples	% of Samples
<0.05	9	17
0.05 - 0.25	27	53
0.25 - 0.50	8	15
<0.5	8	15

Geometric Mean (Arsenic Concentration) 0.17 μg/ml

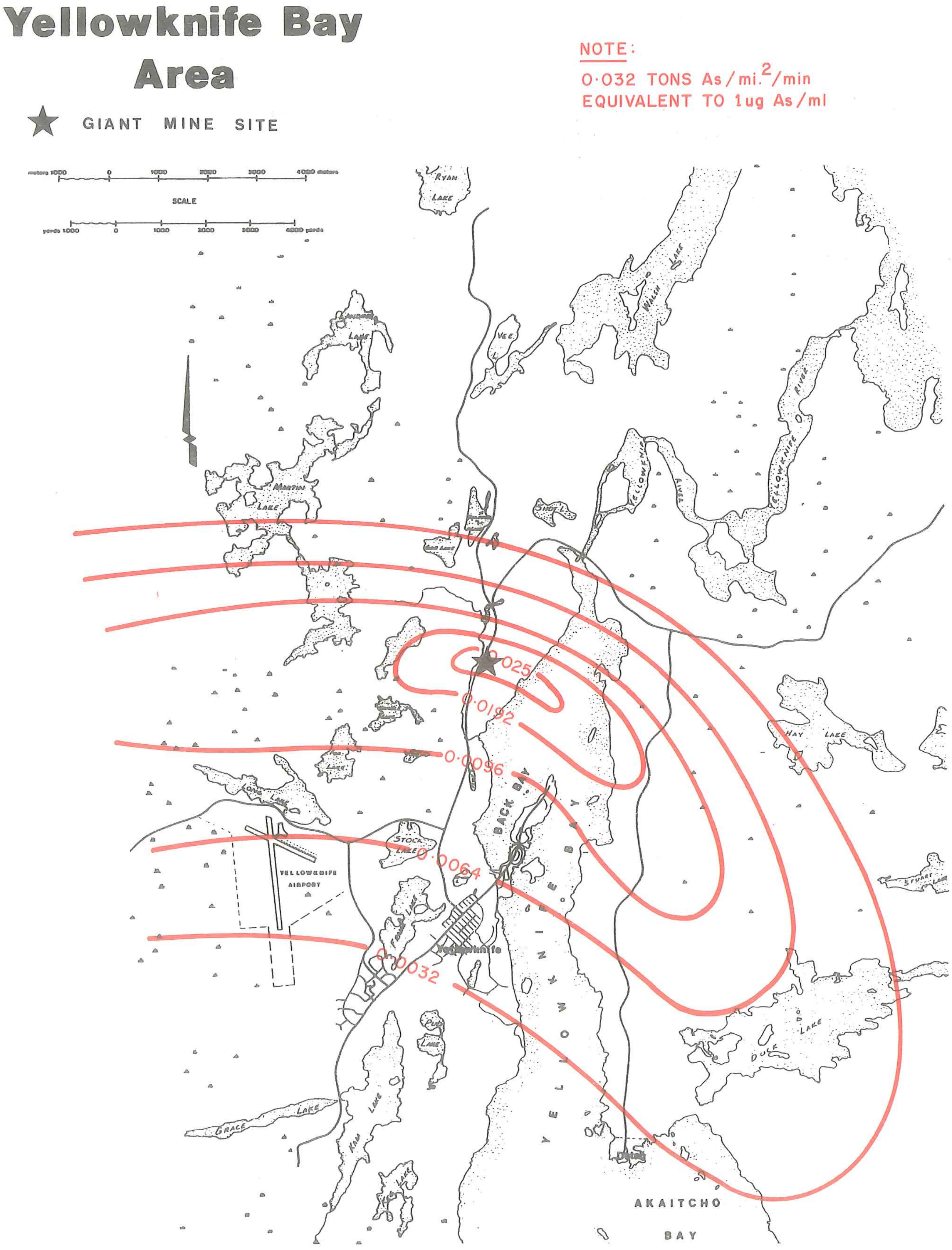


FIGURE 7. ARSENIC ISOPLETHS FOR SNOW SURVEY - 1975

TABLE 7 FREQUENCY DISTRIBUTION OF TOTAL ARSENIC DEPOSITION RATE

Total Arsenic Deposition Rate (Range) (Tons As/Sq Mile/Month)	Number of Sampling Sites	% of Samples
<0.0016	9	17
0.0016 - 0.0080	27	53
0.0080 - 0.0160	8	15
>0.0160	8	15

Geometric Mean (Total Arsenic Deposition Rate) - 0.0053 tons/sq mile/month arsenic/sq mile/month was obtained as the overall total arsenic deposition rate. These calculations reflect best estimates and hence prudence should be exercised in quoting these deposition rate figures.

4.3 Comparison of Results from Scoop and Core Samples

Concentrations of arsenic in the scoop samples were significantly higher than those detected in the core samples. In review, 57% of the scoop samples contained greater than 0.5 mg/l, while only 15% of the core samples exceeded this value. Furthermore, the mean levels of arsenic were approximately three times greater in the scoop than in the core samples.

Since the analytical methods used for the two sets of samples were different, a further series of samples and known standards were analyzed by both laboratories using their respective techniques. The results of this work are given in Table 8, and indicate reasonably good correlation. Hence one may conclude that the difference in arsenic concentrations is not due to analytical reasons but rather due to the difference in sampling procedures employed.

Values of pH detected in the two sets of samples were similar, and while the percentage of scoop samples which did not conform to the Canadian Drinking Water Standards was greater than that of the core samples, the difference was not of major significance.

4.4 Summary

While no attempt has been made to estimate the total quantity of arsenic which was contained in the snow cover of the Yellowknife area during the course of this survey, it is evident that this quantity is large. Since springtime melting of snow at this latitude normally occurs briefly and suddenly, it is suspected that much of the arsenic contained in the snow is delivered to the streams, lakes and rivers of the Yellowknife area, and ultimately to Great Slave Lake. This probably accounts for elevated concentrations of arsenic previously measured at breakup in the surface waters of Yellowknife Bay (1).

While the concentrations of other contaminating elements and compounds in snow were generally lower than those of arsenic, significant levels of toxicants such as lead were nevertheless detected. Synergistic interactions between heavy metals in aquatic ecosystems are known

TABLE 8. COMPARISON BETWEEN ATOMIC ABSORPTION SPECTROSCOPY AND VASAK AND SEDIVEC COLORIMETRY FOR ARSENIC ANALYSIS

Sample No.	Type of Sample	Vasak & Sedivec Colorimetry by EPS Regional Lab µg As/ml	Atomic Absorption Spectroscopy	
			by EPS Regional Lab µg As/ml	by EC Water Quality Lab µg As/ml
*1	Std. <0.01	<0.02	<0.01	<0.0005
*2	Std. 0.5	0.47	0.44	0.46
3	Core	0.07	0.10	0.075
4	Scoop	0.005	0.04	0.3
*5	Std. 0.05	0.04	0.045	0.044
6	Scoop	0.05	0.07	0.047
7	Scoop	0.08	0.05	0.036
8	Scoop	12.0	14.5	11.0
9	Core	18.0	19.5	16.0
*10	Std. 5.00	4.4	5.7	5.1
11	Core	0.07	0.07	0.068
12	Core	0.04	0.04	0.020
*13	Std. 23.00	17.0	17.5	23.0
14	Scoop	0.16	0.03	0.027
15	Core	0.21	0.37	0.09
16	Core	0.22	0.16	0.20
*17	Std. 4.00	4.0	4.3	3.9
18	Scoop	0.04	<0.01	0.02
*19	Std. 0.80	0.81	0.78	0.80
20	Scoop	0.05	0.02	0.02

*Standards - known concentration

TABLE 8. - Continued

Sample No.	Type of Sample	Vasak & Sedivec Colorimetry by EPS Regional Lab µg As/ml	Atomic Absorption Spectroscopy	
			by EPS Regional Lab µg As/ml	by EC Water Quality Lab µg As/ml
*21	Std. 0.25	0.34	0.25	0.27
*22	Std. 0.06	0.05	0.07	0.062
23	Core	0.12	0.06	0.08
24	Core	0.05	0.03	0.041
25	Core	2.8	2.0	2.1
*26	Std. 0.04	0.03	0.03	0.046
*27	Std. 0.13	0.24	0.11	0.14
*28	Std. 0.40	0.33	0.36	0.41
29	Core	0.06	0.04	0.028
30	Core	0.05	0.06	0.05
31	Scoop	0.27	0.24	0.24
32	Scoop	0.95	1.2	1.5
*33	Std. 1,69	1.3	1.4	2.1
34	Scoop	0.16	0.16	0.10
*35	Std. 11.00	8.9	10.0	13.0
36	Scoop	0.15	0.05	0.056
37	Core	0.11	0.06	0.65
38	Scoop	0.12	0.10	0.096
*39	Std. <0.01	<0.02	<0.01	<0.0005
*40	Std. <0.01	<0.02	<0.01	<0.0005

*Standards - known concentration.

to occur. Therefore, while the concentrations of individual substances may appear to be low, they may still have undesirable effects in combination with other toxicants.

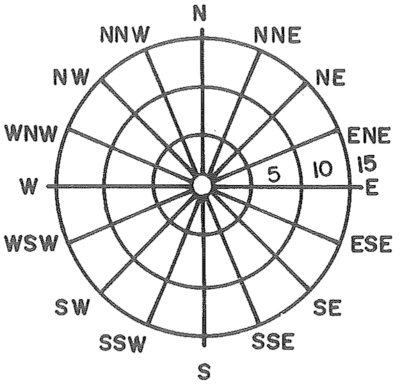
The results of this survey clearly implicate Giant Yellowknife Mines Limited as the primary source of arsenic contributed to the snow cover of the Yellowknife area. This was expected, since the roasting operation at Giant is the major source of arsenic emissions to the atmosphere at the present time. While no attempt was made to identify the zone of contamination from arsenic emissions in and around the Yellowknife area, the detection of elevated levels of arsenic at considerable distances indicates that the total area of contamination is quite large.

REFERENCES

1. "Chemical and Biological Characteristics of Seepages from tailings area at Giant Yellowknife Mines Ltd. into Great Slave Lake, N.W.T. 1974". R.R. Wallace and M.J. Hardin. EPS-5-NW-74-1.
2. O'Toole J.J., Clark R.G., Malaby K.L., and Trauger A.L. "Environmental Trace Element Survey at a Heavy Metals Refining Site"., 1970.
3. "Technical Data Summary, Arsenic in the Yellowknife Environment, Yellowknife, N.W.T. January 1977". Ad hoc Standing Committee on Arsenic.
4. "Standard Methods for the Examination of Water and Wastewater". Method 427C. Turbidimetric method, Pg. 496 - 498.
5. "Analytical Methods for Atomic Absorption Spectrophotometry". Perkin Elmer Corporation 1971.
6. Traversy W.J., "Methods for Chemical Analysis of Waters and Wastewaters". Pg. 74 - 79.

APPENDIX I

Wind Rose Data



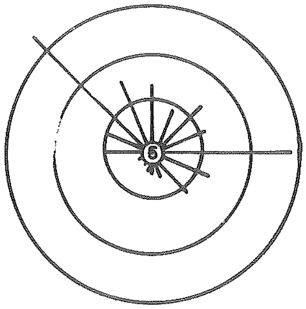
WIND ROSE (1955 - 1966)
% FREQUENCY OF DIRECTION
YELLOWKNIFE

LEGEND

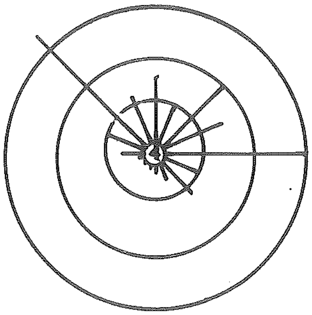
WMS — WIND MEAN SPEED (M.P.H.)

③ REPRESENTS % CALM

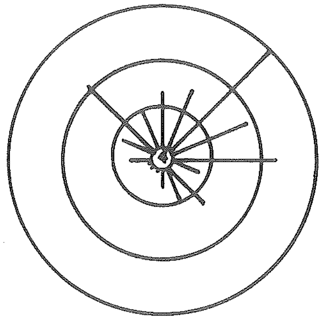
JANUARY WMS - 9.1



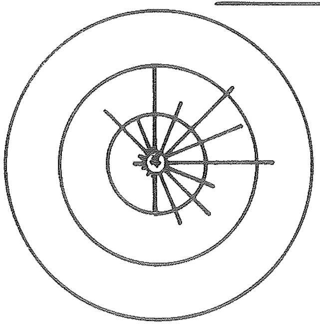
FEBRUARY WMS - 8.4



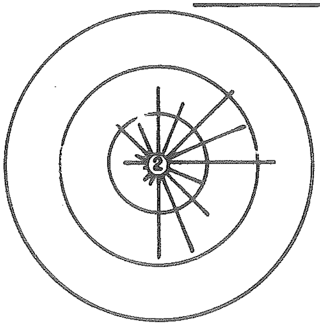
MARCH WMS - 9.4



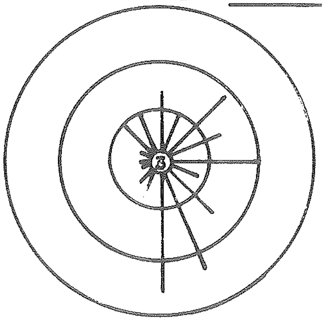
APRIL WMS - 10.9



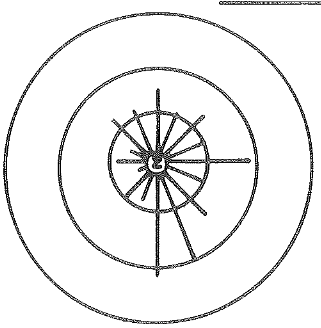
MAY WMS - 11.0



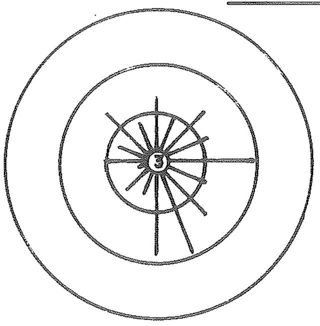
JUNE WMS - 11.2



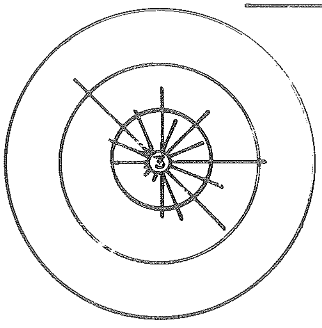
JULY WMS - 10.7



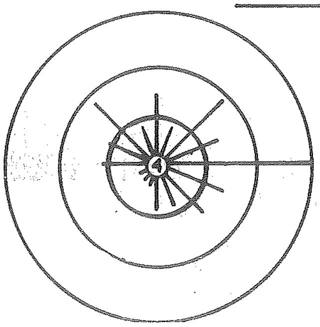
AUGUST WMS - 10.2



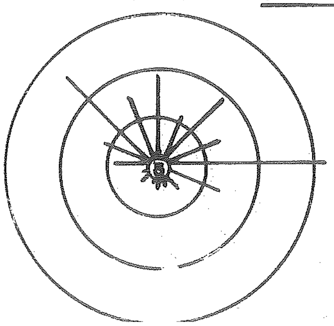
SEPTEMBER WMS - 11.2



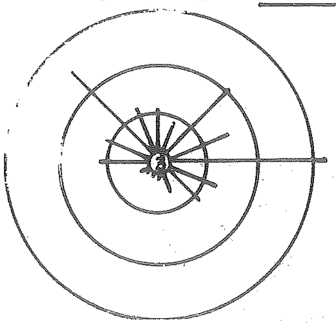
OCTOBER WMS - 11.3

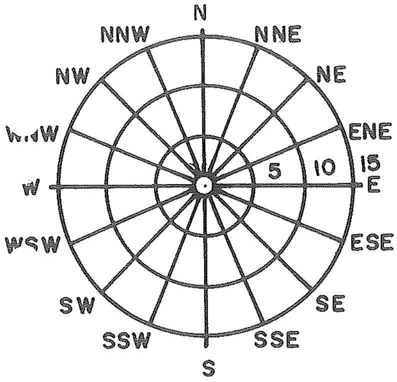


NOVEMBER WMS - 9.9



DECEMBER WMS - 8.8





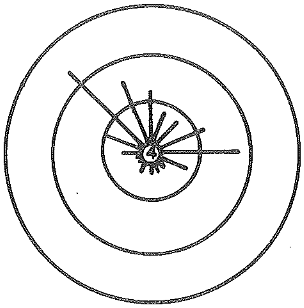
WIND ROSE (1967 - 1972)
% FREQUENCY OF DIRECTION
YELLOWKNIFE

LEGEND

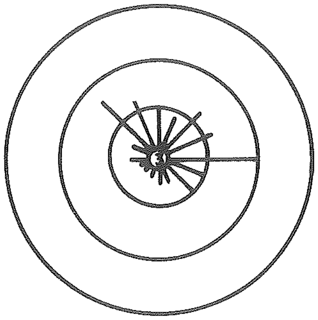
WMS — WIND MEAN SPEED (M.P.H.)

③ REPRESENTS % CALM

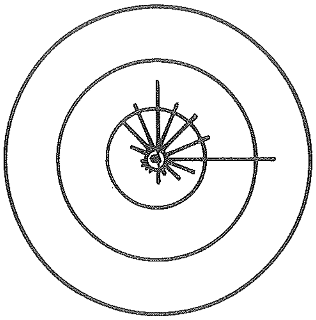
JANUARY WMS - 8.4



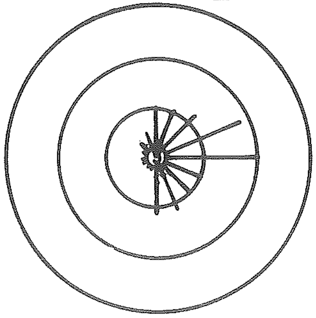
FEBRUARY WMS — 8.8



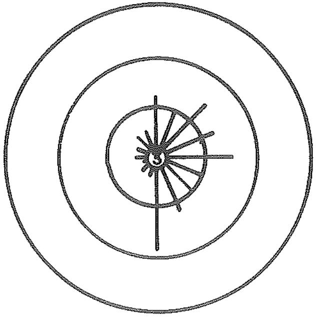
MARCH WMS — 9.0



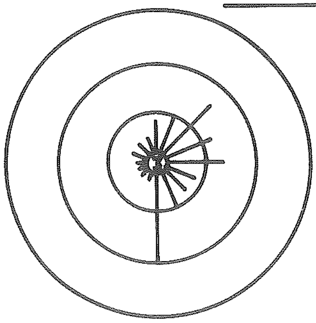
APRIL WMS — 10.0



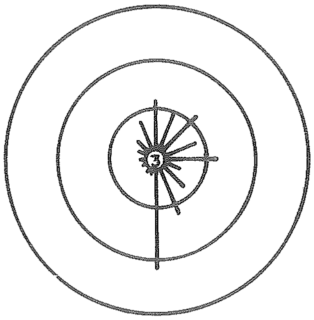
MAY WMS — 10.4



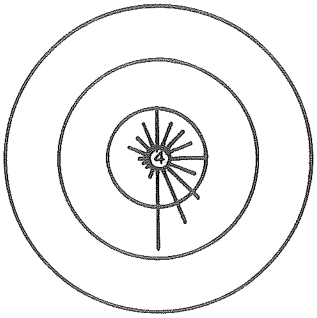
JUNE WMS — 10.7



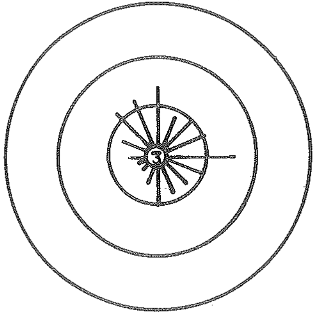
JULY WMS — 10.0



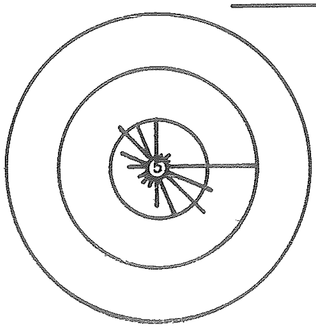
AUGUST WMS — 9.9



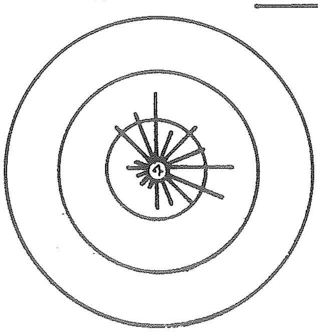
SEPTEMBER WMS — 10.3



OCTOBER WMS — 9.8



NOVEMBER WMS — 9.4



DECEMBER WMS — 7.9