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A Report on Air Quality in Yellowknife, Northwest Territories

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ABSTRACT

Two gold mines, namely Giant Yellowknife Mines Ltd. and Con Mine Ltd. operate in the immediate vicinity of Yellowknife. Since 1950, studies, by various federal departments and individual researchers, have endeavoured to identify and quantify arsenic in the Yellowknife environment.

The objective of this report is to provide information on the quality of the ambient air in the Yellowknife area, with major emphasis being placed on the magnitude of arsenic present in suspended and settleable particulates. Sulfur dioxide and lead levels were also measured. The results indicate an average arsenic concentration of 0.08 micrograms arsenic per cubic meter of air and an average arsenic deposition rate of 10 pounds of arsenic per square mile per month. Further, the results also indicate that 24-hour total suspended particulate levels exceed the maximum acceptable National Air Quality Objective approximately 10% of the time whereas sulfur dioxide levels are basically within the maximum acceptable National Air Quality Objectives.

There is a need to clarify the significance of the arsenic levels measured with respect to its impact on the environment. In addition, an effective and accurate method for determining ambient concentrations of total arsenic needs to be identified.

The results of some previous studies by Health and Welfare have been provided for comparison purposes. Certain details regarding Giant Yellowknife Mines Ltd., such as the nature of the ore, the process and a chronology of air pollution control measures implemented, have also been provided for information purposes.

RÉSUMÉ

Deux mines d'or, la Giant Yellowknife Mines Ltd et la Con Mine Ltd, sont en exploitation dans le voisinage immédiat de Yellowknife où, depuis 1950, plusieurs ministères fédéraux ainsi que des chercheurs ont tenté d'identifier et de doser l'arsenic.

L'objet du présent rapport est de fournir des renseignements sur la qualité de l'air ambiant de la région de Yellowknife; il met l'accent sur la quantité d'arsenic présente tant dans les particules en suspension que dans celles qui se déposent. Les résultats indiquent une concentration moyenne de 0,08 microgramme de cet élément toxique par mètre cube d'air et un rythme moyen de dépôt de 10 livres par mille carré et par mois. Ils rélèvent également que les concentrations de particules totales en suspension pour 24 heures dépassent la norme maximale acceptable, définie comme objectif national de qualité de l'air, environ 10 p. 100 du temps. Les concentrations de plomb et de dioxyde de soufre ont également été mesurées; celles de ce dernier composé sont conformes à l'objectif national.

Il est nécessaire, du point de vue des répercussions sur l'environnement, de préciser l'importance des concentrations d'arsenic mesurées et de trouver une méthode efficace et exacte d'en doser la présence totale.

Les résultats de certaines études antérieures du ministère de la Santé nationale et du Bien-être social sont fournies pour fins de comparaison.

Certains détails concernant le Giant Yellowknife Mines Ltd, comme la nature du minerai, le type de traitement et la chronologie des étapes de la lutte contre la pollution de l'air sont également donnés.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

1. Annual geometric mean arsenic concentrations in ambient air (measured by the hi-vol method) were 0.08, 0.09 and 0.06 ug arsenic/m^3 for 1973, 1974, and 1975 respectively.

2. Individual 24-hr arsenic concentrations in ambient air varied from less than 0.01 to 3.91 ug arsenic/m^3.

3. Approximately 10% of the time, 24-hr total suspended particulate levels for 1973, 1974 and 1975 exceed the maximum acceptable National Air Quality Objectives.

4. The maximum tolerable National Air Quality Objective for total suspended particulates was exceeded approximately 2% of the time.

5. For 1975, an annual geometric mean lead concentration in ambient air of 0.03 ug lead/m^3 was recorded.

6. Lead levels measured are not considered significant in comparison to levels at other locations across Canada.

7. The amount of arsenic in the vapour state defied accurate determination due to limitations in sampling techniques.

8. An arithmetic mean of 11 tons/sq mile/month was obtained as the total particulate deposition rate.

9. An arithmetic mean of 10 lbs/sq mile/month was obtained as the arsenic deposition rate.

10. Giant Mine is a primary and fugitive source of arsenic in settleable particulates.

11. Con Mine continues to be a source of fugitive arsenic emissions.

12. Annual arithmetic mean sulfur dioxide concentrations in ambient air do not exceed the maximum desirable National Air Quality Objective.

13. Hourly ambient sulfur dioxide concentrations occasionally exceed the maximum desirable National Air Quality Objective.

14. Hourly ambient sulfur dioxide concentrations rarely exceed the maximum acceptable National Air Quality Objective.

RECOMMENDATIONS

1. The question of identifying National Air Quality Objectives for arsenic should be referred to the Federal/Provincial Committee on Air Pollution.

2. An effective and accurate method for determining ambient concentrations of total arsenic needs to be identified.

3. Total suspended particulate levels occasionally exceed the maximum tolerable National Air Quality Objective, hence an investigation of the problem should be initiated soon with the intent of rectifying the situation.

4. The significance of historical and present arsenic deposition rates on the Yellowknife environment requires additional study Specific areas which need to be examined further include, accumulation in soils, quantities in spring run-off and effects on local vegetation.

5. Since measured sulfur dioxide concentrations in ambient air are basically within the maximum acceptable National Air Quality Objectives, it is recommended that the sulfur dioxide monitoring program in Yellowknife be terminated for the time being.

1 INTRODUCTION

The history of the Northwest Territories indicates that gold mining was responsible for opening the northern frontier to development. Two such mining operations, namely Giant Yellowknife Mines Ltd. and Con Mine Ltd. exist in the immediate vicinity of Yellowknife.

The Giant Yellowknife Mine is located on the north shore of Great Slave Lake, approximately three miles from the City of Yellowknife. It commenced production in 1948. It was initially owned and operated by Ventures Ltd. until 1962 when it became part of the Falconbridge Group of Companies. Air Pollution control measures were initiated in 1951, and refined over the period 1951 to 1962 to improve collection efficiency of arsenic emissions. Details regarding the nature of the ore, the process and a chronology of air pollution control measures implemented has been provided in Appendix I.

Con Mine Ltd. is located approximately half a mile south of the City of Yellowknife. Until 1970, the off-gases from their roasting operations were scrubbed and the arsenic bearing sludge was discharged to open pits. Since 1970, Con Mine has discontinued roasting operations, and hence their process is no longer a source of atmospheric arsenic emissions; however, the arsenic sludge pits and tailings disposal areas continue to be sources of fugitive arsenic emissions.

Since 1950 the Department of Health and Welfare (H & W) has conducted a number of studies to document the health implications of arsenic exposure on the local population; some of the studies related to arsenic concentrations in the ambient air. Baker and De Villiers of H & W in 1966 concluded that, while inhaled arsenical particulates may have a minor contributory role in the incidence and prevelance of respiratory diseases in Yellowknife, it was probably of less importance than other environmental factors (1).

The objective of this report is to document the quality of the ambient air in the Yellowknife area, with major emphasis being directed to identifying the magnitude of arsenic present in suspended and settleable particulates.

2. AMBIENT AIR MONITORING PROGRAM

As a result of public concern over the levels of arsenic in the air, water, and land environment around the Yellowknife area, H & W have carried out a number of studies over the past 20 years. Renewed interest in the ambient air levels of arsenic was expressed by H & W in 1973 and their concern was conveyed to the Department of Fisheries and the Environment (DFE). Existing information on ambient air levels of arsenic obtained from dustfall studies carried out during 1950-63 as well as stack emission information from Giant Mines for the period 1950-74 and from Con Mines for the period 1950-70 have been summarized under Appendices II and III, respectively.

In response to H & W's concerns, EPS on behalf of DFE initiated a 12-week study (March 12 - June 4, 1973) to obtain additional data on ambient air levels of arsenic in the Yellowknife area. A portion of the data obtained during this first phase of the study had to be invalidated because of analytical discrepancies. The study was reconstituted in April 1974 and data for the period April 21, 1974 to February 10, 1975 was obtained under Phase II. A separate survey to monitor ambient carbon monoxide levels in Yellowknife was conducted by EPS between January and May of 1975. It concluded that carbon monoxide levels in Yellowknife were well below the maximum acceptable National Air Quality Objectives.

Towards the end of 1974 EPS was planning a basic environmental survey in Yellowknife for the summer of 1975 including an expanded air monitoring program. The concerns raised by the January 8, 1975 CBC program "As It Happens" provided additional impetus to the commitment of resources. As a result, the Yellowknife Environmental Survey (YES) became a reality. During the initial phases of YES the need for an interdepartmental co-ordinating body was identified and hence the Standing Committee on Arsenic in Yellowknife was formed. It has representatives from DFE, H & W, DINA, NWT government, City of Yellowknife and from the mining industry. Specific areas on which emphasis was directed included: air quality, water quality, human health, industrial hygiene, fisheries, wildlife, soils and vegetation. Since a substantial amount of information was already available on human health, industrial hygiene, fisheries and water

quality from previous studies, the major emphasis under YES was directed towards obtaining information on air quality, wildlife, soils and vegetation. EPS undertook to implement a Giant Yellowknife stack emission survey, an expanded air monitoring project and an investigation of soils and vegetation.

Under the auspices of the Yellowknife Environmental Survey, the existing ambient air monitoring project comprising of three high volume (hi-vol) samplers was expanded into a network of nine sampling stations to monitor suspended particulates. In addition, a network of 22 dustfall jars was set up to monitor settleable particulates. Further, analyzers were set up at three different sites to monitor ambient concentrations of sulphur dioxide. The general topographical features of the Yellowknife area and the overall ambient air sampling sites have been depicted geographically in Figures 1 & 2 respectively.

3 SUSPENDED PARTICULATES

3.1 Sampling Procedure and Location of Sites

Suspended particulate matter was collected utilizing high volume (hi-vol) samplers, since most of the arsenic emitted to the atmosphere from the roasting operation was expected to be in particulate form (2). Since Con Mine had discontinued roasting operations in 1970, Giant Mine was the major source for the purposes of this study. An analysis of the wind data for the periods 1955-66 and 1967-72 indicated that the prevailing wind direction during the summer (May - August) is in the south to east quadrant, whereas during the winter (September - April) the prevailing winds are either from the northwest or the east. Wind rose information for Yellowknife has been provided in Appendix IV. Having identified the source and prevailing wind directions, the location of sampling sites were chosen; the availability of electricity was an additional major constraint that had to be contended with. Brief descriptions on the locations of the high volume sampling stations have been provided in Appendix V.

Under Phase I of the study (from March 12 - June 4, 1973), high volume samples were randomly collected for 24-hr durations. The latter portion of the data obtained under this phase (April 27 - June 4, 1973)

FIGURE 1 TOPOGRAPHICAL FEATURES

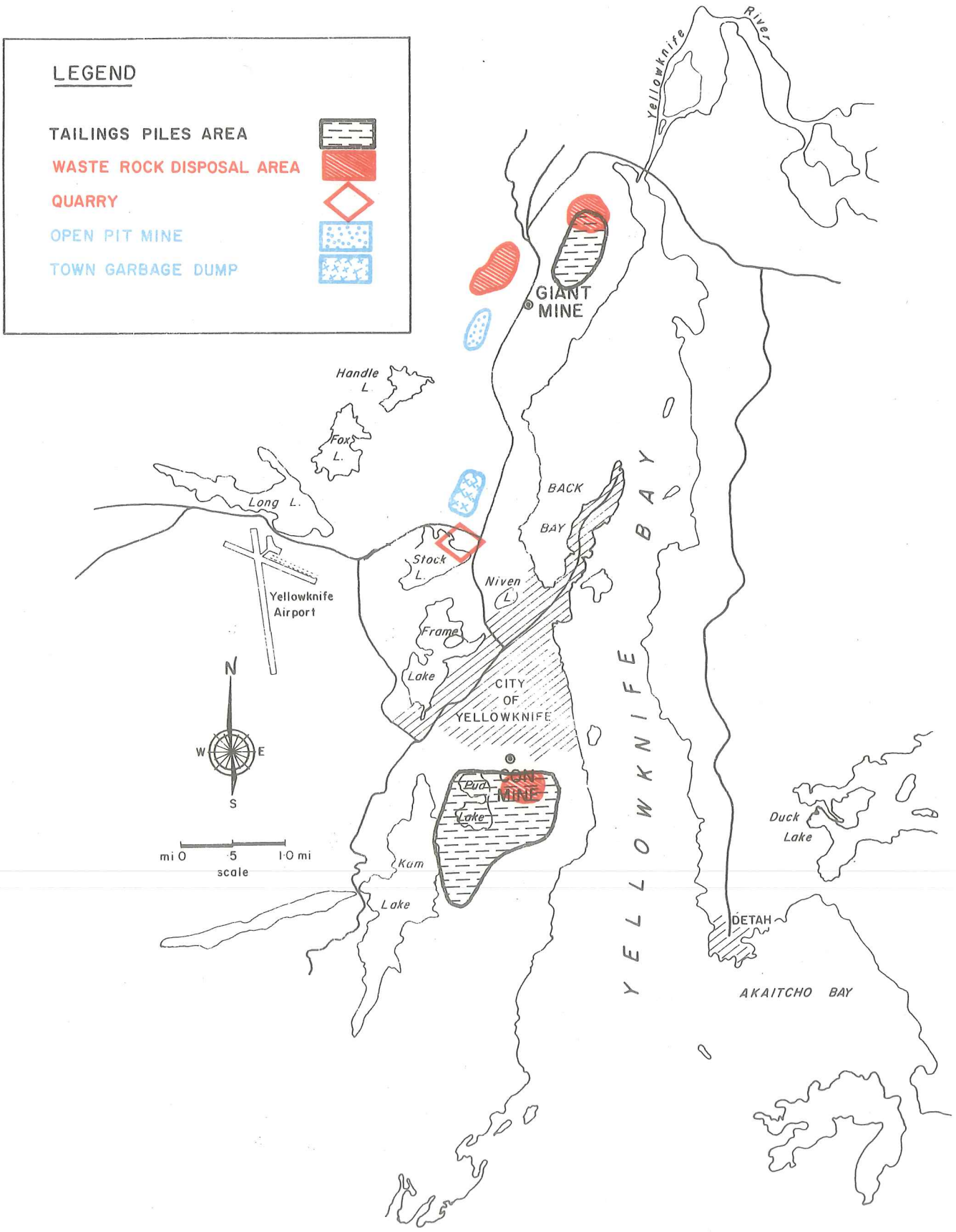
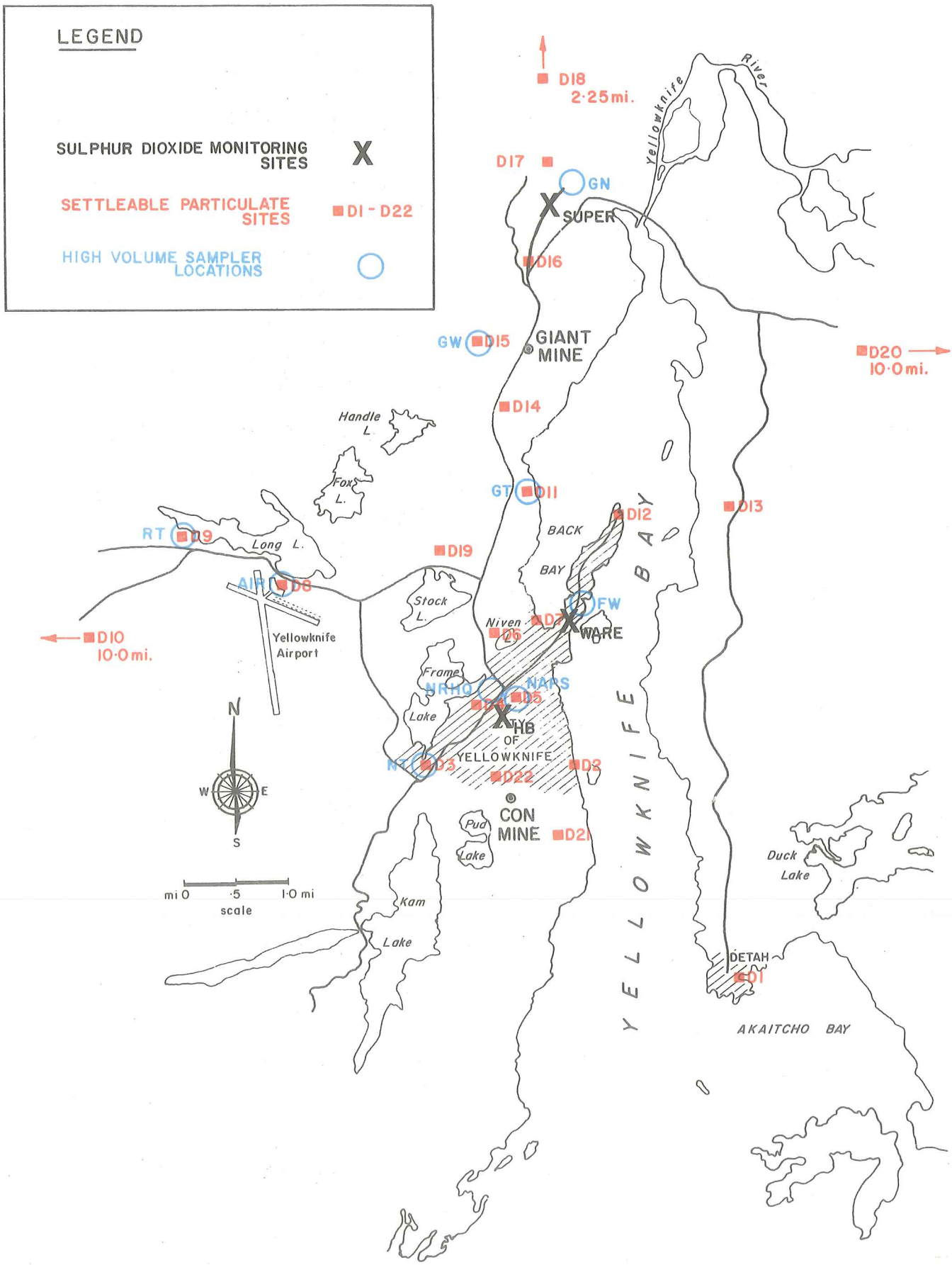


FIGURE 2 OVERALL AMBIENT AIR SAMPLING SITES



had to be invalidated due to analytical discrepancies. Under Phase II of the study (from April 12, 1974 February 10, 1975), high volume samples were collected randomly for 24 hr, 72 hr, 96 hr, and 120 hr intervals, sometimes in conjunction with bubbler samples, in an attempt to quantify the proportion of arsenic trioxide in the vapour phase. Bubbler samples for the above varying durations were collected during the period May 23, 1974 to August 2, 1974. Under Phase III of the study (from February 11, 1975 to October 30, 1975) high volume samples were collected randomly for 24-hr durations. Since the bubbler samples under Phase II were inconclusive in qualifying the proportion of arsenic trioxide in the vapour phase a further attempt was made under Phase III to improve, by chemical means, the collection efficiency of the hi-vol method for total arsenic (particulates as well as vapour). The technique consisted of impregnating a hi-vol filter with a 10 percent solution of polyethyleneimine. The impregnated filter was dried and then placed in a two-layer hi-vol system with a porous fiberglass screen separating the regular untreated filter at the top from the impregnated filter at the bottom. Sixteen 24-hr samples were collected utilizing this sampling procedure.

3.2 Sample Analysis

Exposed hi-vol filters from Phase I of the study were initially analyzed for arsenic by the Chemistry Division of the Air Pollution Control Directorate in Ottawa, utilizing both x-ray fluorescence as well as Vasak and Sedivec (pyridine) techniques. Suitable aliquots of some of the samples were also analyzed by the EPS regional laboratory in Edmonton as a cross-reference.

Samples collected during the second half of Phase I, i.e. for the period April 27, 1973 to June 4, 1973, were directed to the EPS regional laboratory in Edmonton for analysis utilizing the Vasak and Sedivec (chloroform) method. Results obtained by the regional laboratory were inconsistent and did not compare well with results obtained by the Chemistry Division in Ottawa, and hence have been invalidated.

Exposed hi-vol filters from Phase II of the study were jointly analyzed for arsenic by Chemistry Division, Ottawa, and the EPS regional

laboratory in Edmonton, utilizing the Vasak and Sedivec (pyridine) technique. The Chemistry Division also conducted x-ray fluorescence determinations. The results between the two laboratories as well as between the two techniques employed, correlate well. Chemistry Division subsequently discontinued the more time-consuming colorimetric method, and hence only performed x-ray fluorescence determinations for arsenic. As indicated earlier, under the quality assurance program, a certain number of bubbler samples were collected, using impinger type bubblers containing 1% sodium hydroxide solution, in an attempt to quantify vapour phase arsenic concentrations. These samples were analysed by the Chemistry Division for arsenic utilizing both the Vasak and Sedivec (pyridine) and x-ray fluorescence techniques. The amount of arsenic collected in the bubbler samples was too small for accurate determination and therefore inconclusive.

Under Phase III of the study, exposed hi-vol filters were analyzed for arsenic under contractual arrangements by Northern Environmental Consultants of Edmonton, utilizing the x-ray fluorescence technique. Duplicate analyses were performed for each sample and the results obtained were highly consistent. In addition, approximately 10% of the samples were also analyzed by the EPS Regional Laboratory in Edmonton, utilizing the Vasak and Sedivec (pyridine) technique. The results of these quality assurance checks indicate a good correlation (see Appendix VI). As indicated earlier, sixteen 24-hr samples, utilizing the chemically impregnated filter, were collected in an attempt to increase the collection efficiency of the hi-vol method for total arsenic. These samples were analyzed by the EPS Regional Laboratory in Edmonton utilizing the Vasak and Sedivec (pyridine) technique. The results indicate that qualitatively collection efficiency is increased; however, quantitatively the data is inconclusive. The results have been summarized in Appendix VI.

3.3 Results and Discussion

A frequency distribution of the arsenic measurements from all three phases of the study has been presented in Table 1. The results show that elevated arsenic levels were detected more frequently at stations GT & GW which are in close proximity to Giant's roaster stack. This confirmed our assumption that Giant was the main source of arsenic emissions to the ambient air.

TABLE 1

FREQUENCY DISTRIBUTION OF ARSENIC CONCENTRATIONS IN AMBIENT AIR

Station*	Year	Number of Samples	Frequency Distribution (No. of occurrences) <0.1	0.1-0.49	0.5-0.99	>1.0 (ug As/m^3)**	(in ug As/m^3) Min	Max	Avg
GT	1973	17	8	7	2	0	<0.01	0.95	0.10
	1974	57	21	26	6	4	<0.01	1.34	0.12
	1975	80	51	25	2	2	<0.01	3.16	0.06
AIR	1973	15	11	3	1	0	<0.01	0.70	0.06
	1974	63	41	21	1	0	<0.01	0.52	0.06
	1975	80	71	6	0	3	<0.01	1.40	0.04
NRHQ	1973	18	10	8	0	0	<0.01	0.42	0.09
	1974	62	39	22	1	0	<0.01	0.54	0.08
	1975	78	64	13	1	0	<0.01	0.59	0.04
RT	1975	49	44	5	0	0	<0.01	0.30	0.02
NT	1975	47	41	5	1	0	<0.01	0.53	0.03
FW	1975	45	35	10	0	0	<0.01	0.31	0.03
GW	1975	52	17	16	5	4	<0.01	0.62	0.13
GN	1975	43	36	6	1	0	<0.01	0.61	0.02
NAPS	1975	50	43	7	0	0	<0.01	0.31	0.03

* Please refer to Appendix V for Station identification and location.
**ug/m^3 = micrograms per cubic meter.

Existing Air Quality Limits for Arsenic: (24-hour average)

British Columbia Objective	1.0 ug/m^3
U.S.S.R. Standard	3.0 ug/m^3
Czechoslovakia Standard	3.0 ug/m^3

NOTE: No national air quality objectives for arsenic have been developed. We are unaware of the criteria used in developing the B.C., U.S.S.R. and Czechoslovakia limits, hence the scientific validity of the limits is unknown.

TABLE 2

FREQUENCY DISTRIBUTION OF TOTAL SUSPENDED PARTICULATES IN AMBIENT AIR

Station	Year	Number of Samples	Frequency Distribution (No. of occurrences)			(ug/m^3)		
			<120 (ug/m^3)	>120 (ug/m^3)	>400 (ug/m^3)	Min	Max	Avg
GT	1973	17	17	0	0	8	58	30
	1974	57	56	1	0	3	252	30
	1975	80	67	13	1	<1	622	34
AIR	1973	15	15	0	0	11	114	37
	1974	63	63	0	0	<1	68	19
	1975	80	75	5	1	3	401	25
NRHQ	1973	18	13	5	0	9	240	50
	1974	62	51	11	0	7	249	46
	1975	78	60	18	5	5	488	51
RT	1975	49	45	4	0	<1	305	18
NT	1975	47	27	20	2	5	451	74
FW	1975	44	38	6	0	1	261	32
GW	1975	42	32	10	0	<1	296	32
GN	1975	43	41	2	0	<1	263	12
NAPS	1975	50	40	10	1	11	425	73

NATIONAL AIR QUALITY OBJECTIVES FOR SUSPENDED PARTICULATE MATTER

Maximum Desirable Level	60 ug/m^3 annual average
Maximum Acceptable Level	70 ug/m^3 annual average
	120 ug/m^3 24-hour average
Maximum Tolerable Level	400 ug/m^3 24-hour average

TABLE 3

FREQUENCY DISTRIBUTION OF LEAD CONCENTRATIONS IN AMBIENT AIR - 1975

Station	Number of Samples	Frequency Distribution (No. of Occurrences)		(in ug Pb/m^3)		
		<0.10 (ug Pb/m^3)	>0.10 (ug Pb/m^3)	Min	Max	Avg
GT	50	47	3	<0.01	0.12	0.03
AIR	54	54	0	<0.01	0.08	0.03
NRHQ	49	43	6	<0.01	0.13	0.04
RT	49	49	0	<0.01	0.05	0.02
NT	47	45	2	<0.01	0.11	0.03
FW	44	43	1	<0.01	0.11	0.03
GW	42	42	0	<0.01	0.07	0.02
GN	43	43	0	<0.01	0.06	0.02
NAPS	45	44	1	<0.01	0.17	0.05

NOTE: Average lead concentrations in ambient air of 0.5 ug/m^3 and maximum lead concentrations in ambient air of around 5 ug/m^3 have been routinely measured at other locations across Canada. National Air Quality Objectives for lead concentrations in ambient air have not been developed.

TABLE 4

FREQUENCY DISTRIBUTION OF TOTAL SUSPENDED PARTICULATES, ARSENIC AND LEAD IN AMBIENT AIR FOR ALL STATIONS

Year	1973	1974	1975
Number of Hi-vol samplers	3	3	9
Total Suspended Particulates in Ambient Air (ug/m^3)			
Number of samples <120	45	170	428
>120	5 (10%)	12 (6.6%)	85 (16.6%)
≥400	0	0	10 (2%)
Min	9	<1	<1
Max	240	252	622
Avg	39	32	39
Number of 24 hour samples collected	50	182	513
Arsenic Concentrations in Ambient Air (ug/m^3)			
Number of samples <0.1	29	101	402
0.1-0.49	18	69	93
0.5-0.99	3	8	10
≥1.0	0	4	9
Min	<0.01	<0.01	<0.01
Max	0.95	1.34	3.91
Avg	0.08	0.09	0.06
Lead Concentrations in Ambient Air ($ug\ Pb/m^3$)			
Min			0.01
Max			0.17
Avg			0.03
Number of 24 hour samples collected			423

Further, each of the hi-vol samples collected under all three phases of the study was analyzed for total suspended particulates utilizing the gravimetric method. The data has been summarized in Tables 2 and 4. On reviewing Tables 2 and 4, one observes that the maximum tolerable National Air Quality Objective for total suspended particulates was exceeded approximately 2% of the time during 1975 and that the 24-hour maximum acceptable level was exceeded approximately 10%, 7%, and 17% of the time during 1973 1974, and 1975 respectively. These high levels are more indicative of fugitive sources of particulate emissions in the vicinity of the sampling stations, such as gravel roads, construction, open pit mining and tailings areas.

In addition, each of the hi-vol samples collected under Phase III of the study were also analyzed for lead using the x-ray fluorescence technique. The results have been summarized in Tables 3 and 4. The lead levels measured are not considered significant in comparison to other locations in Canada.

Results indicating arsenic concentrations in excess of 0.5 ug/m^3 (micrograms of arsenic per cubic meter of air) have been studied in greater detail, and an attempt was made to correlate the results with wind speed and direction, temperature and cloud cover. The analysis with respect to wind direction clearly identifies Giant Mine as the major source. In addition, the meteorological information indicates that 97% of these higher arsenic concentrations occur during a cloudy or overcast day. Details have been provided in Appendix VII.

The use of the hi-vol sampler as an accurate and hence, representative method for determining ambient concentrations of total arsenic has been recently questioned by various researchers (3, 4, 5, 6, 7). Their concern is based on the assumption that inadequate consideration is given to the physical properties of arsenic compounds. Attempts at quantifying the amount of arsenic in the vapour phase, both through bubbler samples collected under Phase II as well as through chemically impregnated filter samples collected under Phase III, have failed to indicate the presence of significant amounts of arsenic in the vapour phase. Qualitatively, some of the arsenic does exist in the vapour phase; however, quantitatively the data is inconclusive (the results have been summarized in Appendix VI).

3.4 Conclusions

1. Annual geometric mean arsenic concentrations in ambient air (measured by the hi-vol method) were 0.08, 0.09 and 0.06 ug arsenic/m^3 for 1973, 1974, and 1975 respectively.

2. Individual 24-hr arsenic concentrations in ambient air varied from less than 0.01 to 3.91 ug arsenic/m^3.

3. Approximately 10% of the time, 24-hr total suspended particulate levels for 1973, 1974 and 1975 exceed the maximum acceptable National Air Quality Objectives.

4. The maximum tolerable National Air Quality Objective for total suspended particulates was exceeded approximately 2% of the time.

5. For 1975, an annual geometric mean lead concentration in ambient air of 0.03 ug lead/m^3 was recorded.

6. Lead levels measured are not considered significant in comparison to levels at other locations across Canada.

7. The amount of arsenic in the vapour state defied accurate determination due to limitations in sampling techniques.

3.5 Recommendations

1. The question of identifying National Air Quality Objectives for arsenic should be referred to the Federal/Provincial Committee on Air Pollution.

2. An effective and accurate method for determining ambient concentrations of total arsenic needs to be identified.

3. Total suspended particulate levels occasionally exceed the maximum tolerable National Air Quality Objective, hence an investigation of the problem should be initiated soon with the intent of rectifying the situation.

4 SETTLEABLE PARTICULATES

4.1 Sampling Procedure and Location of Sites

Settleable particulate measurements on a monthly basis were initiated in June 1975 and concluded in October 1975. The program consisted of a network of twenty-two dustfall stations. The locations of the sampling sites were chosen taking into consideration criteria such as: wind rose data, location of high volume samplers, fugitive sources

and human activity. Brief descriptions on the location of these dust fall sampling stations have been provided in Appendix XI.

The sampling equipment at each site consisted of 7.3 quart nalgene container mounted either on a stand or a pole. Figures 3a, b, and c, depict details of the container and the mounting procedures. The containers were normally 4 to 6 feet above ground level, however security requirements at times necessitated higher elevations. Details with respect to elevation above ground level have also been provided in Appendix XI.

The settleable particulates collected in the containers were transferred into plastic bottles along with the washings and forwarded to the EPS regional laboratory in Edmonton for analysis.

4.2 Sample Analysis

In the laboratory, each sample was split into a soluble and an insoluble fraction utilizing filtration principles. The soluble fraction was subsequently placed in a steam bath and a solid residue was obtained on evaporation. The total deposition rate was then obtained by simple gravimetric analysis and has been expressed in terms of tons/sq mile/month.

The arsenic deposition rate was obtained by dissolving both the soluble and insoluble residues in 1% sodium hydroxide solution and subsequent analysis for arsenic utilizing the Vasak and Sedivec (pyridine) technique. The arsenic deposition rate has been expressed in terms of lbs/sq mile/month.

A quality check was conducted on the laboratory procedure adopted for the analysis of deposition rate samples. The results indicate good recovery for total particulates in samples. Further, the quality check indicates that while arsenic recovery is enhanced by drying at 25^{o}C as opposed to drying at 105^{o}C, the difference is not very significant. Details have been provided in Appendix XII.

4.3 Results and Discussion

The results obtained from the settleable particulates part of the program have been presented as raw data in Appendix XII. Total deposition rates have been summarized by station in Table 5. Arsenic deposition rates have also been summarized by station in Table 6. The re-

FIGURE 3 a
FIELD CONTAINER

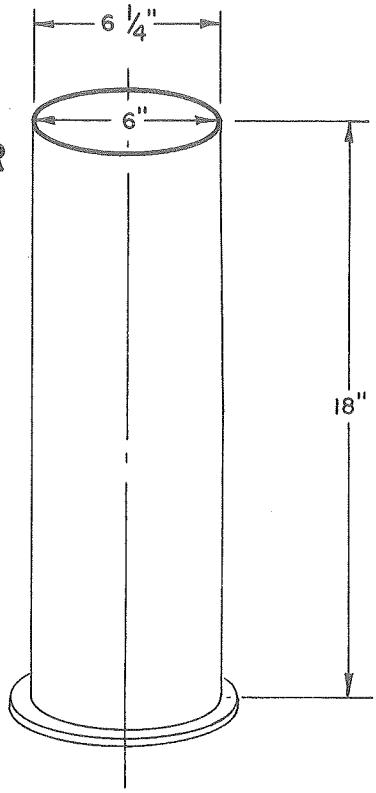
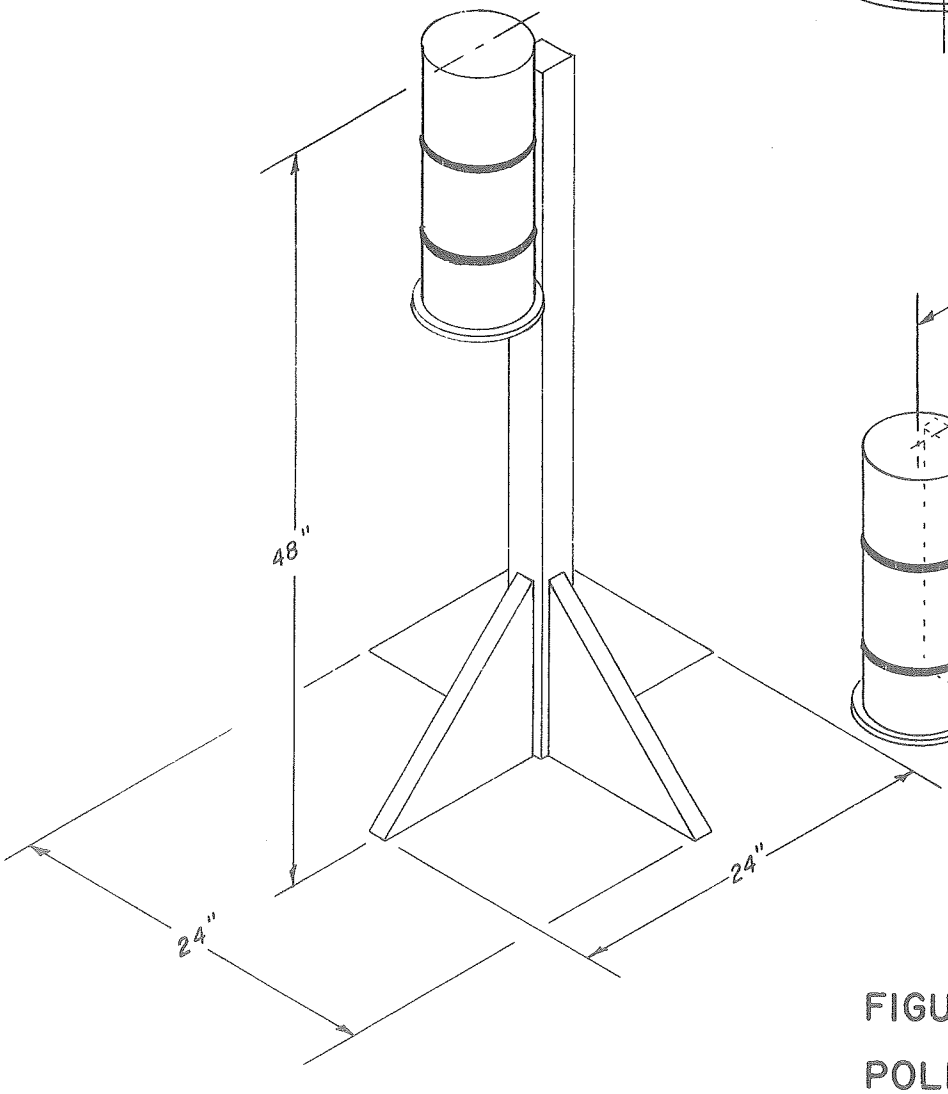


FIGURE 3 b
STAND APPARATUS WITH CONTAINER



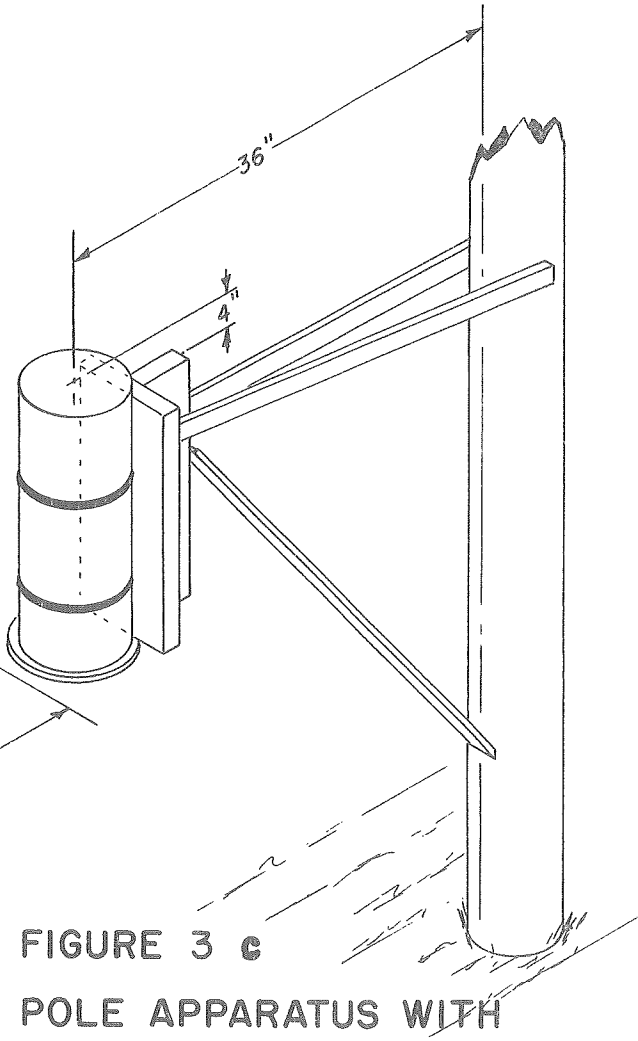


FIGURE 3 c
POLE APPARATUS WITH CONTAINER

TABLE 5

MEAN TOTAL DEPOSITION RATE BY STATION
JUNE - OCTOBER 1975 (TONS/SQ MILE/MONTH)

Station	Arithmetic Mean	Geometric Mean
D1	5.87	5.50
D2	13.3	5.55
D3	9.02	8.62
D4	6.76	6.26
D5	21.5	19.2
D6	5.56	4.75
D7	7.60	6.05
D8	12.0	10.6
D9	2.77	2.19
D10	7.73	4.70
D11	7.44	6.32
D12	7.77	6.40
D13	3.37	2.41
D14	23.3	20.1
D15	45.3	10.3
D16	19.9	14.2
D17	11.8	4.89
D18	4.78	3.44
D19	2.72	2.38
D20	8.82	5.69
D21	9.32	4.74
D22	4.84	3.97
Overall Mean	10.98	5.98

TABLE 6

MEAN ARSENIC DEPOSITION RATE BY STATION
JUNE - OCTOBER 1975 (LBS/SQ MILE/MONTH)

Station	Arithmetic Mean	Geometric Mean
D 1	2.61	2.44
D 2	8.12	7.01
D 3	4.77	4.26
D 4	3.02	2.69
D 5	7.50	6.55
D 6	3.65	2.09
D 7	3.72	3.32
D 8	4.39	4.19
D 9	2.19	1.79
D10	3.13	1.43
D11	7.12	6.42
D12	4.30	3.77
D13	2.50	1.52
D14	27.32	25.0
D15	31.94	25.0
D16	37.44	29.6
D17	9.42	8.22
D18	7.62	6.27
D19	4.42	4.28
D20	3.34	3.16
D21	33.88	8.87
D22	2.87	2.79
Overall Mean	9.79	4.83

sults indicate an overall average total deposition rate of 10.98 tons/sq mile/month and an overall arsenic deposition rate of 9.79 lbs/sq mile/month. On reviewing the arsenic deposition rates by station one observes that stations D14, D15 and D16 which surround Giant Mine are consistently high. This further confirms Giant Mine as the primary source of arsenic emissions. In addition, a very high arsenic deposition rate during June 1974 was obtained at station D21 which is located near Con Mine adjacent to the tailings area and the arsenic pits. This indicates that Con Mine's tailings area and the arsenic pits continue to be significant sources of fugitive arsenic emissions.

4.4 Conclusions

1. An arithmetic mean of 11 tons/sq mile/month was obtained as the total particulate deposition rate.

2. An arithmetic mean of 10 lbs/sq mile/month was obtained as the arsenic deposition rate.

3. Giant Mine is a primary and fugitive source of arsenic in settleable particulates.

4. Con Mine continues to be a source of fugitive arsenic emissions.

4.5 Recommendations

The significance of historical and present arsenic deposition rates on the Yellowknife environment requires additional study. Specific areas which need to be examined further include, accumulation in soils, quantities in spring run-off and effects on local vegetation.

5 SULFUR DIOXIDE

5.1 Sampling Procedure and Location of Sites

Continuous ambient air monitoring for sulfur dioxide was initiated in April 1973 with the installation of one Philip's monitor on the roof of the Hudson's Bay Store in downtown Yellowknife. The monitoring program was expanded under YES to three locations in June, 1975, with the installation of two additional Philip's monitors. One of the monitors was located at the EPS warehouse on the peninsula off Latham Island whereas the second monitor was located at the Super Crest Buildings approximately

one and a half miles north of Giant Mine. These sampling sites were chosen after due consideration of factors such as wind rose data, availability of electrical power, accessibility, adequate shelter and security. Additional information on the location of the above sampling stations has been provided in Appendix XI.

The sampling equipment at each site comprised of a Philip's model PW9700 coulometric monitor along with a strip chart recorder. Weekly calibrations and annual maintenance programs were carried out in accordance with manufacturer's specifications. Sulfur dioxide levels recorded on the charts were extracted and compiled manually.

5.2 Results and Discussion

An annual summary of sulfur dioxide concentrations measured has been presented in Table 7. The annual arithmetic mean values for all three years 1973 to 1975 do not exceed the annual level specified under the maximum desirable National Air Quality Objective (NAQO) for sulfur dioxide. However, individual 1-hr values exceed the 1-hr objective approximately 0.12%, 0.25% and 0.48% of the time monitored during 1973, 1974, and 1975 respectively. Further, four individual 1-hr values even exceeded the 1-hr maximum acceptable NAQO for sulfur dioxide.

Results indicating sulfur dioxide levels in excess of 0.17 ppm (maximum desirable NAQO) have been studied in greater detail and an attempt was made to correlate the results with time of day, wind speed and direction. Details have been provided in Appendix XII. On analysis, the wind direction correlation data clearly identifies Giant Mine as the major source of sulfur dioxide emissions. Further, the data shows that levels in excess of 0.17 ppm are predominantly obtained during the evening hours with 50% of the occurrences taking place between 4 p.m. and 11 p.m. and 35% of the occurrences taking place between 7 p.m. and 11 p.m. The data has been presented graphically in Figure 4.

The wind velocity correlation data has also been presented graphically in Figure 6. It clearly indicates that the majority of sulfur dioxide levels greater than 0.17 ppm were obtained at wind speeds of 5 to 8 mph.

TABLE 7

ANNUAL SUMMARY OF SULPHUR DIOXIDE CONCENTRATIONS

Year	1973	1974	1975
# of monitors operational	1	1	3
Actual # of hourly concentrations measured*	4080	6095	7960
Theoretical # of hourly concentrations possible*	6580	8730	12410
Percentage of time operational	62%	70%	64%
Frequency distribution of 1-hr sulfur dioxide levels: a) <0.17 ppm b) 0.17 - 0.34 ppm c) >0.34 ppm	 4075 5 0	 6080 13 2	 7922 36 2
Max. (ppm)	0.25	0.42	0.40
Min. (ppm)	<0.005**	<0.005	<0.005
Annual arithmetic mean (ppm) - all stations	<0.010	<0.010	0.010

* rounded off to nearest 5 units
**lower detectable limit for the Philips monitor
number

FIGURE 4

SO_2 HOURLY DATA CORRELATED WITH HOUR OF DAY
(for all locations)

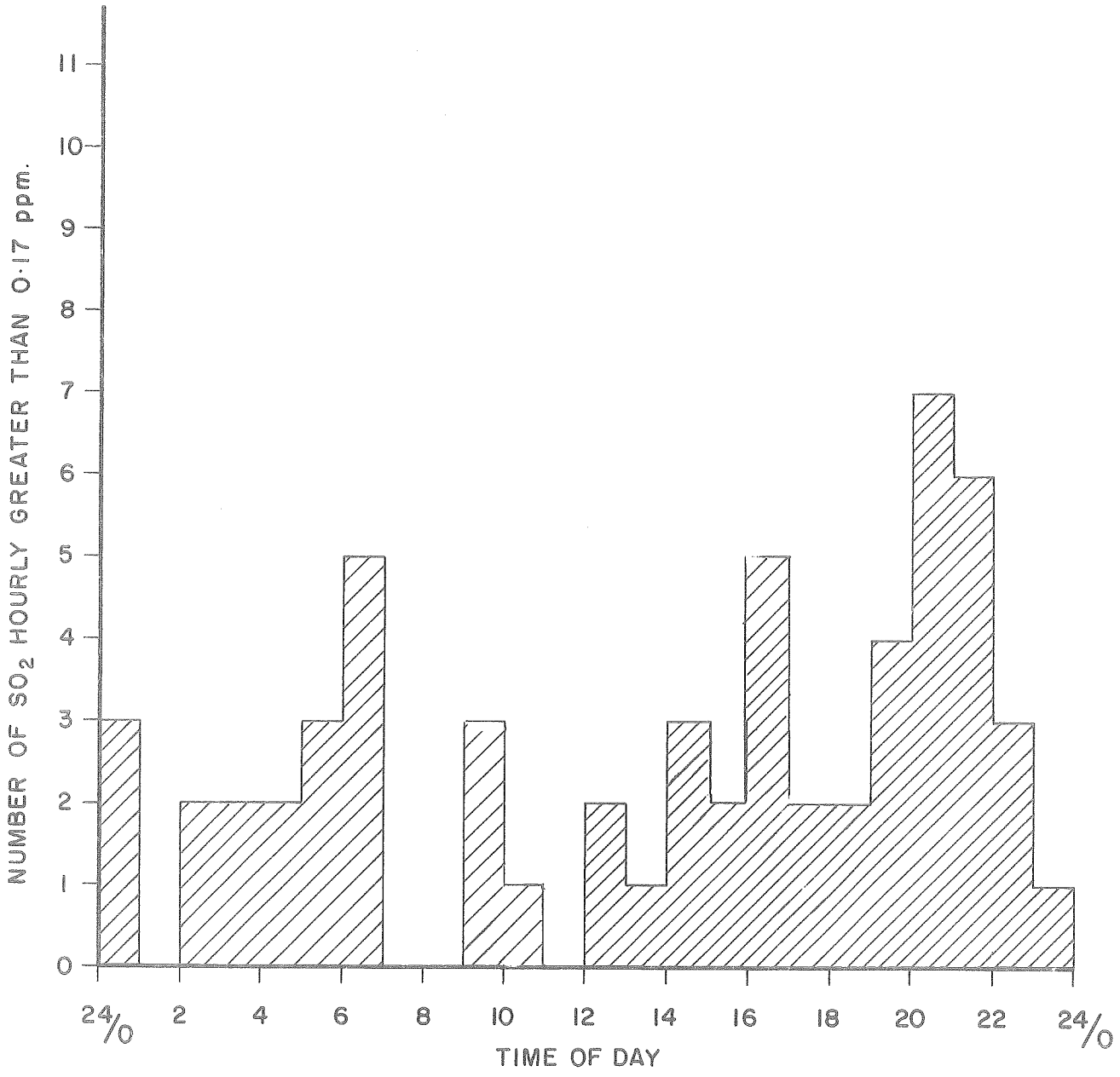
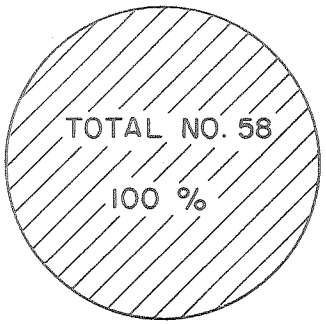
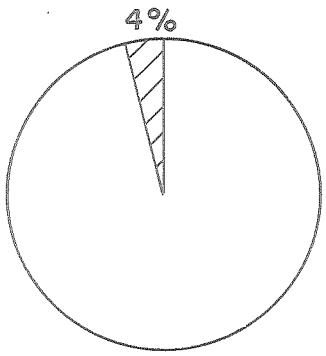


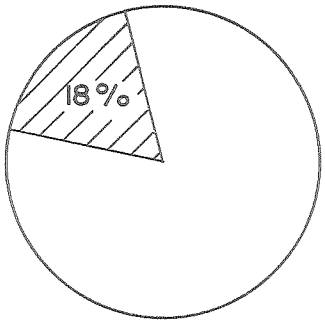
FIGURE 5

SO_2 HOURLY DATA GREATER THAN 0·17 CORRELATED WITH WIND VELOCITY

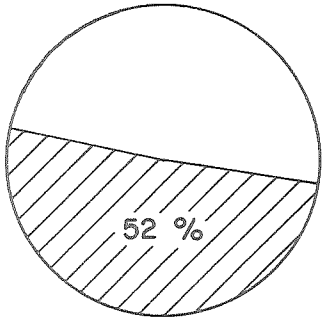




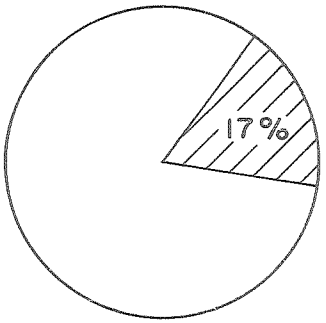
CALM



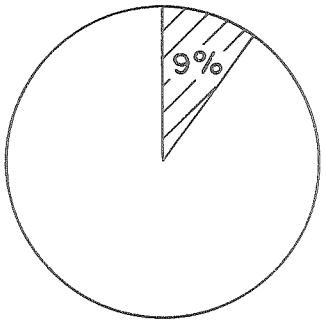
1-4 mph.



5-8 mph.



9-12 mph.



13-16 mph.

5.3 Conclusions

1. Annual arithmetic mean sulfur dioxide concentrations in ambient air do not exceed the maximum desirable National Air Quality Objective.

2. Hourly ambient sulfur dioxide concentrations occasionally exceed the maximum desirable National Air Quality Objective.

3. Hourly ambient sulfur dioxide concentrations rarely exceed the maximum acceptable National Air Quality Objective.

5.4 Recommendations

Since measured sulfur dioxide concentrations in ambient air are basically within the maximum acceptable National Air Quality Objectives, it is recommended that the sulfur dioxide monitoring program in Yellowknife be terminated for the time being.

REFERENCES

1. de Villiers, A.J. and P.M. Baker, Department of National Health and Welfare, Environmental Health Directorate, Occupational Health Division, "An Investigation of the Health Status of Inhabitants of Yellowknife, Northwest Territories".

2. Air Pollution Control Directorate, Environmental Protection Service, Ottawa, "Standard Reference Method for the Determination of Suspended Particulates (by the Hi-Vol Method)", Report No. EPS-1-AP73-2.

3. Lao, R.C., et al., "Efficiency of Collection of Arsenic (Trioxide) in Hi-Vol Sampling", Science of the Total Environment, Vol. 2, (1974).

4. Pupp, C., and R.C. Lao, "Equilibrium Vapour Concentrations of Some Polycyclic Aromatic Hydrocarbons, Arsenious Oxide and Selenious Oxide and the Collection Efficiencies of these Air Pollutants", Atmospheric Environment, Vol. 8, Page 915, (1974).

5. Dubois, L., "Status Report On Arsenic in Yellowknife", Internal Report, Chemistry Division, Air Pollution Control Directorate, Ottawa, (1975).

6. Personal communique from Puget Sound Air Pollution Control Agency, Seattle, Washington, (1975).

7. Subcommittee on Arsenic, Committee on Medical and Biologic Effects of Environmental Pollutants, National Research Council, "Arsenic", National Academy of Sciencies, Washington, D.C., (1976).

APPENDIX I

GIANT YELLOWKNIFE MINES LTD.

The Nature of the Ore

The ore consists of sericite and chlorite schist containing aproximately 30% quartz with variable amounts of calcium and iron carbonates together with sulphides and sulphosalts. Arsenopyrite and pyrite comprise the bulk of the sulphides. Stibnite and sulphantimonides of lead, iron and copper form the remainder.

Typical Analysis - Gold: 0.50 oz/ton
Iron: 7.18%
Sulphur: 2.85%
Arsenic: 1.32%
Antimony: 0.18%

Process Description

Ore hoisted from underground is reduced to 3/8" size by jaw and cone crushers in a plant located on the surface. After crushing, the ore is transported by conveyor to the mill building where it is stored in four 500-ton bins. It is then ground to a very fine size (55% minus 200 mesh) by two 8' x 10' ball mills each operating in closed circuit with a 72" Akins classifier (flow diagram has been provided).

The resulting pulp is pumped at 44% solids into a bulk flotation circuit where about 84% of the waste rock is removed. This waste is pumped to the backfill plant where it is de-slimed and stored ready for use as mine backfill. The reject portion is directed to the tailings pond.

The remainder, or flotation concentrate, containing the gold and most of the sulphide minerals, is pumped to the roasting section of the plant for removal of sulphur, arsenic and antimony. The roaster feed is metered at 76% solids into a two-stage fluosolids roaster operating at temperatures in excess of 900^{o}F.

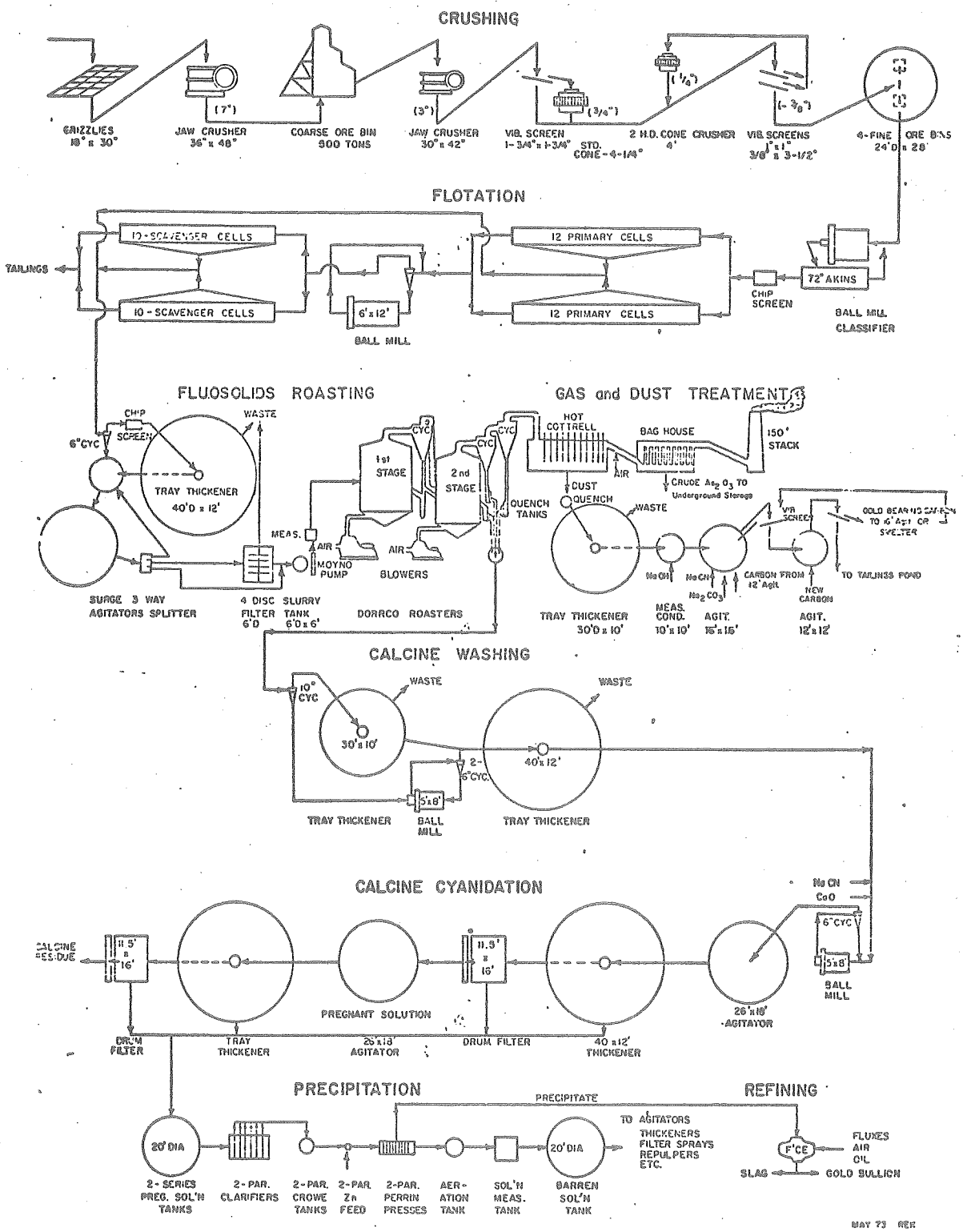
The product of roasting is a porous calcine. The calcine is washed in water and pumped back to the main mill building where sodium cyanide and lime are added. These agents, in the presence of oxygen, dissolve the gold from the calcine. The resulting "pregnant" solution is deoxygenated and gold is precipitated out by adding zinc dust. The precipitate is refined into gold in a tilting bullion furnace.

Wastewater from the calcine wash circuit decant and wash thickners is treated with lime in an agitator and discarded to tails. All wastewaters, because of the arsenic content, are treated with lime to decrease the soluble

GIANT YELLOWKNIFE MINES LTD.

Yellowknife, Northwest Territories

milling flow sheet



MAY 73 REF

arsenic level. Approximately 3000 lbs of lime is added daily to lower soluble arsenic content by about 80%.

Dust from the roasting process is collected in a hot electrostatic precipitator. It is then quenched and gold is extracted by a similar cyanide process but using activated carbon as the collecting agent. About 3% of the total gold output is recovered in this way. The carbon concentrate is sent to the United States for refining at a customs smelter.

As an air pollution control measure, arsenic and antimony oxides given off by the roasting process are collected by cooling the gases from the precipitator plant to 210°F and filtering them through orlon bags. The collected dust is pumped back underground to specially sealed permafrost stopes with displaced air reporting back to the baghouse. The exhaust gases are discharged to the atmosphere through a 150 foot stack. Total recovery of gold from the complex Giant ore is approximately 88.8%.

Chronology of Air Pollution Control Measures

Concern was expressed in 1950 over potential health hazards from the roasting process and associated arsenic fallout (10,000 - 20,000 lbs/day arsenic released to atmosphere). The following remedial measures were initiated in 1951. Air pollution control measures were refined over the period 1951 - 1962 to improve removal of arsenic trioxide from emissions. The reported efficiency of the control equipment is around 96% containment of arsenic from the stack gas emissions.

1951 - Milling capacity of 232 tons/day. Roaster gas cleaning started.

1952 - 150 foot high stack constructed.

1955 - Second electrostatic precipitator installed.

1957 - Milling capacity increased to over 1000 tons/day. Roaster capacity increased to 200 tons/day.

1958 - New two stage fluosolids roaster installed to replace existing roasters. Baghouse dust collected installed for more effective arsenic collection. Arsenic dust stored underground in special stopes.

1962 - Original cold electrostatic precipitator converted to hot electrostatic operation. The same roaster

gas cleaning system has been in use from 1962 to date. The system consists of:

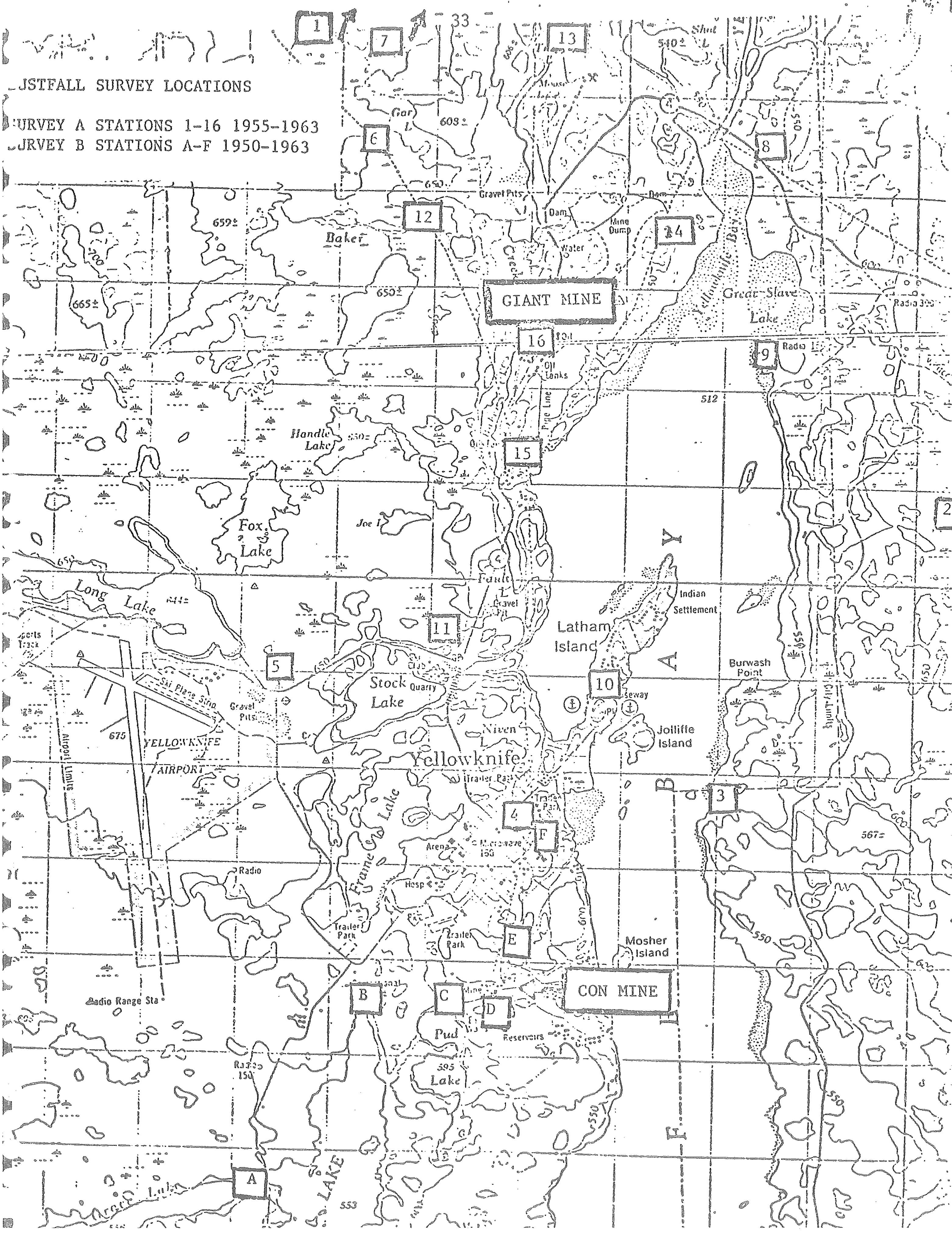
1. Cooling of roaster gases to approximately 700°F.
2. Roaster dust removal in a hot electrostatic precipitator.
3. Recycle of dust to carbon process for gold recovery.
4. Cooling of gas to condense arsenic.
5. Collection of arsenic in a baghouse type collector.
6. Dry pumping and storage of arsenic dust in specially sealed underground stopes (mined out areas).

APPENDIX II

DUSTFALL STUDIES BY NATIONAL HEALTH AND WELFARE

ARSENIC DEPOSITION RATES

1950 - 1963



JSTFALL SURVEY LOCATIONS
URVEY A STATIONS 1-16 1955-1963
JRVEY B STATIONS A-F 1950-1963
GIANT MINE
CON MINE
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
A
B
C
D
E
F
Baker
Gravel Pits
Dam
Mine Dump
Water
Great Slave Lake
Yellowknife Bay
Oil Tanks
Pipe Line
Handle Lake
Fox Lake
Joe L
Long Lake
Fault L
Gravel Pit
Indian Settlement
Latham Island
Burwash Point
Stock Lake
Quarry
Ski Plane Strip
Gravel Pits
YELLOWKNIFE AIRPORT
Airport Limits
City Limits
Niven L
Yellowknife
Trailer Park
Jolliffe Island
Frame Lake
Arena
Microwave
Radio
Hosp
Trailer Park
Mosher Island
Radio Range Sta
Pud Lake
Reservoirs
LAKE
B A Y

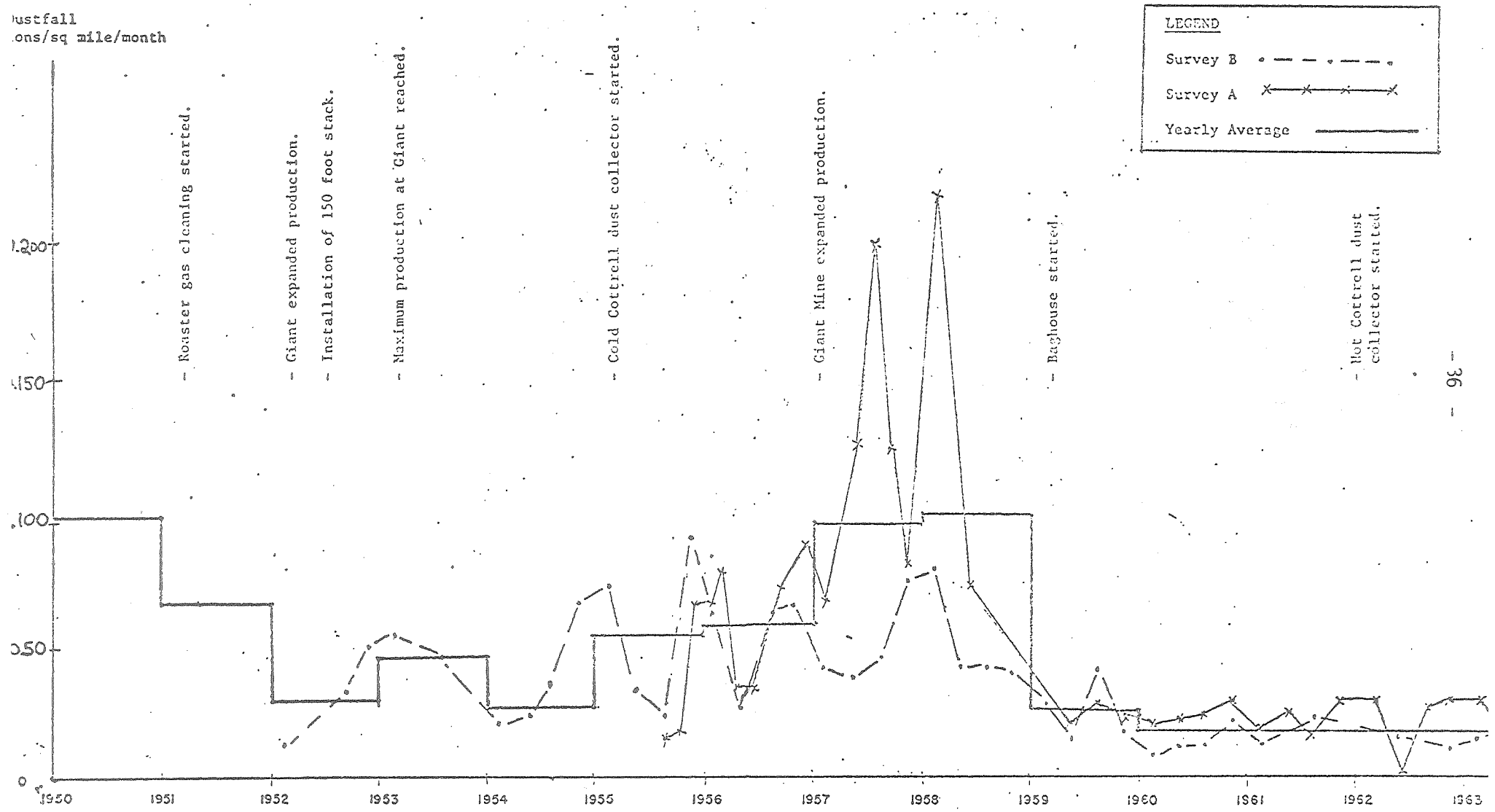
YEARLY ARSENIC DEPOSITION (ALL LOCATIONS)

Year	Tons/sq mile/month
1950	0.103
1951	0.068
1952	0.030
1953	0.047
1954	0.027
1955	0.056
1956	0.059
1957	0.098
1958	0.104
1959	0.026
1960	0.019
1961	0.019
1962	0.019
1963	0.019

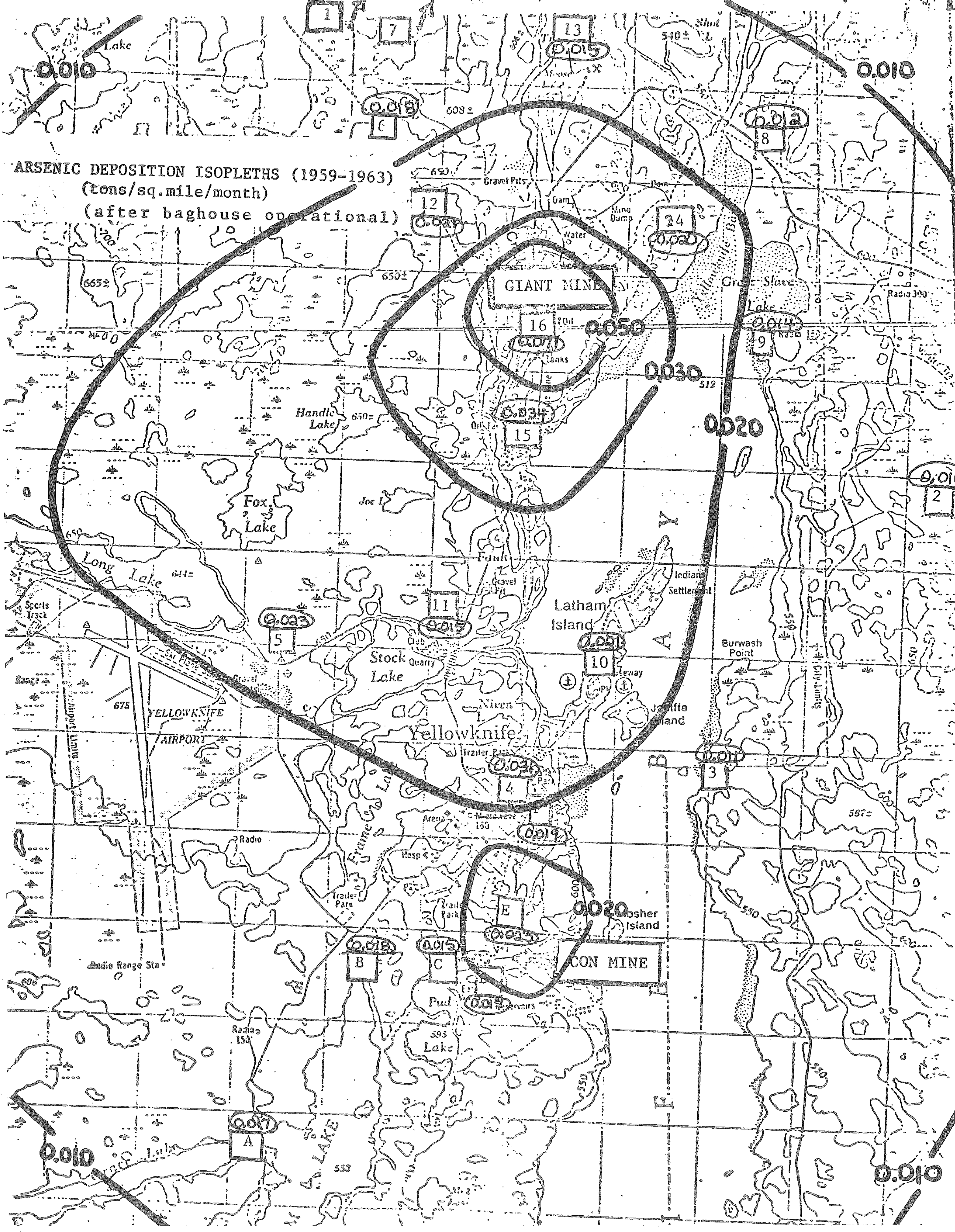
FREQUENCY DISTRIBUTION OF ARSENIC DEPOSITION RATE
(On Yearly Basis)

ARSENIC DEPOSITION RATE
(Tons Arsenic/Sq Mile/Month)

Year	No. of Data Submissions	<0.05	0.05-0.10	0.10-0.15	0.15-0.20	0.20-0.25	>0.25
1951	5	100%	-	-	-	-	-
1952	6	100%	-	-	-	-	-
1953	6	67%	33%	-	-	-	-
1954	6	100%	-	-	-	-	-
1955	16	39%	31%	6%	6%	6%	12%
1956	16	39%	31%	6%	-	12%	12%
1957	22	9%	41%	32%	-	4%	14%
1958	22	23%	55%	9%	-	9%	4%
1959	22	86%	14%	-	-	-	-
1960	22	91%	9%	-	-	-	-
1961	14	93%	7%	-	-	-	-
1962	15	100%	-	-	-	-	-
1963	14	100%	-	-	-	-	-



Graph of Yearly Arsenic Depositions and Giant Yellowknife Operational Characteristics


ARSENIC DEPOSITION ISOPLETHS (1959-1963)
(tons/sq.mile/month)
(after baghouse operational)
GIANT MINE
CON MINE
0.010
0.020
0.030
0.050
1
7
13
0.015
0.018
6
0.012
8
12
0.027
14
0.020
16
0.071
0.014
9
0.034
15
0.01
2
11
0.015
0.023
5
0.021
10
0.011
3
0.036
4
0.019
E
0.023
0.019
B
0.015
C
0.017
0.017
A
Handle Lake
Fox Lake
Long Lake
Joe L.
Stock Lake
Latham Island
Indian Settlement
Burwash Point
Yellowknife
YELLOWKNIFE AIRPORT
Airport Limits
City Limits
Frame Lake
Mosher Island
Pud Lake
LAKE
BAY
Gravel Pits
Mine Dump
Water
Tanks
Quarry
Club
Arena
Hosp
Trailer Park
Radio
Radio Range Sta
Sports Track
Range
Great Slave Lake

APPENDIX III

ARSENIC EMISSIONS SUMMARY

GIANT MINE, 1949 - 1974
CON MINE, 1950 - 1970

STACK EMISSION SUMMARY

GIANT MINE

Year	Arsenic Emissions (lbs/day)	No. Of Data Submissions	Dust Recovery Efficiency	References
1949	(16,000)	-	-	3
1950	(16,000)	-	-	3
1951	(16,000)	-	-	3
1952	-	-	-	-
1953	-	-	-	-
1954	12,000	-	41.8	2
1955	6,400	4	66.5	2
1956	6,000	11	54.6	2
1957	6,500	10	61.6	2
1958	(3,300)	-	-	3
1959	115	7	99.6	2
1960	165	9	99.4	2
1961	(330)	-	-	3
1962	(330)	-	-	3
1963	(330)	-	-	3
1964	690*	4	98.2*	1
1965	-	-	-	-
1966	535*	3	98.3*	1
1967	285*	4	99.0*	1
1968	500*	2	98.8*	1
1969	660*	3	97.7*	1
1970	485	3	98.3	1
1971	1,930	8	93.1	1
1972	875	4	96.5	1
1973	890	5	95.1	1
1974	485	5	98.1	1

* Corrected from previous data

() Estimated

References:
1. Company emission reports.
2. Company emission data as given to N.H. & W.
3. Estimated values from company production data.

STACK EMISSION SUMMARY

CON MINE

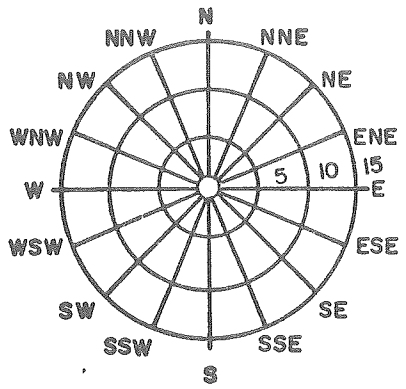
Year	Arsenic Emissions (lbs/day)	Dust Recovery Efficiency	Reference
1949	-	-	-
1950	(200)	(95)	3
1951	(200)	(95)	3
1952	(200)	(95)	3
1953	-	-	-
1954	395	97.8	2
1955	420	98.3	2
1956	410	97.9	2
1957	400	-	2
1958	385	-	2
1959	435	97.8	2
1960	585	97.3	2
1961	(440)	-	3
1962	(440)	-	3
1963	(440)	-	3
1964	295	-	2
1965	370	95.1	2
1966	310	-	2
1967	340	85.2	2
1968	335	-	2
1969	430	-	2
1970	550	86.2	2
1971	Roaster ceased 10/11/70		

References:
1. Company emission reports.
2. Company emission data as given to N.H. & W.
3. Estimated values from company production data.

APPENDIX IV

WIND ROSE DATA FOR YELLOWKNIFE, NWT

1955 - 1972



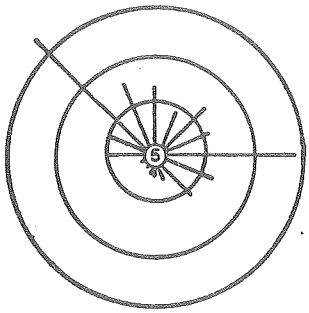
WIND ROSE (1955 - 1966)
% FREQUENCY OF DIRECTION
YELLOWKNIFE

LEGEND

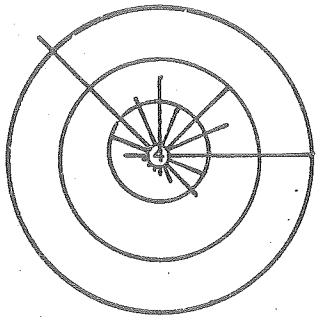
WMS — WIND MEAN SPEED (M.P.H.)

(3) REPRESENTS % CALM

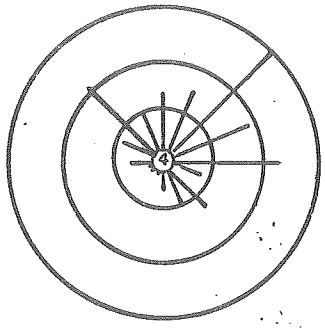
JANUARY WMS - 9.1



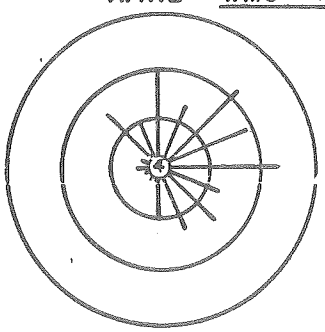
FEBRUARY WMS - 8.4



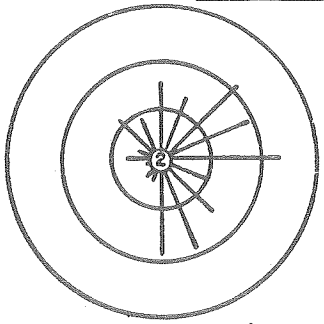
MARCH WMS - 9.4



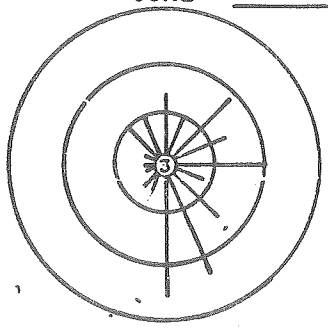
APRIL WMS - 10.9



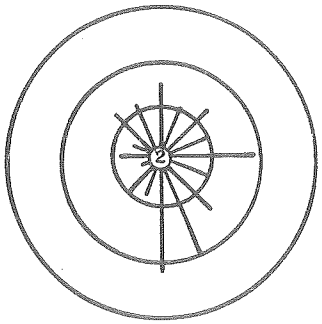
MAY WMS - 11.0



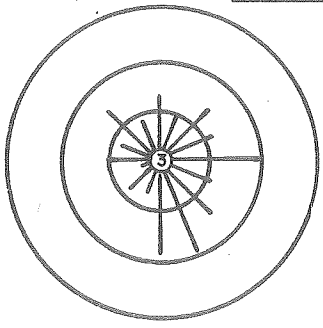
JUNE WMS - 11.2



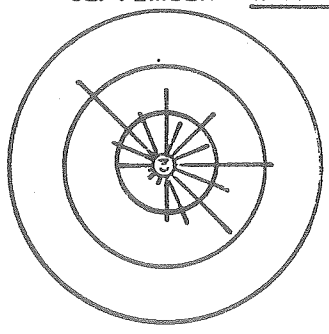
JULY WMS - 10.7



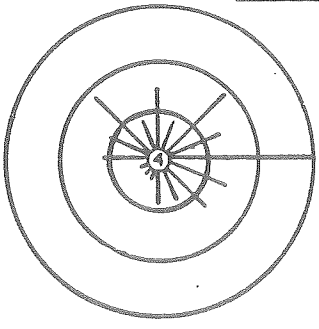
AUGUST WMS - 10.2



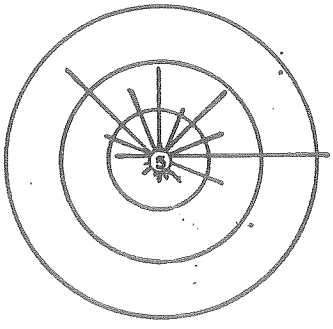
SEPTEMBER WMS - 11.2



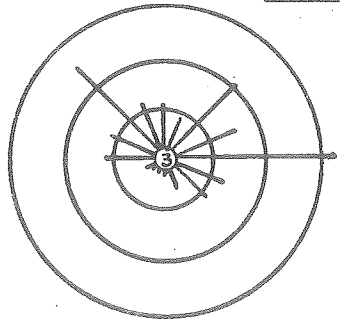
OCTOBER WMS - 11.3

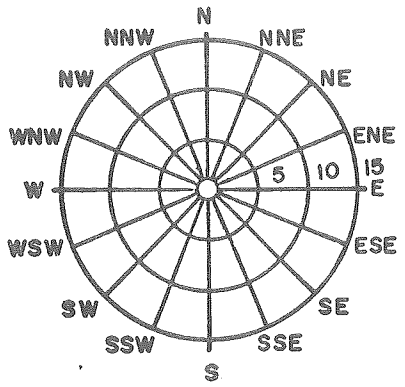


NOVEMBER WMS - 9.9



DECEMBER WMS - 8.8





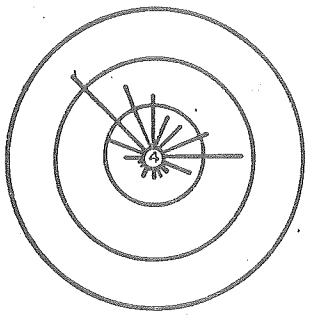
WIND ROSE (1967 - 1972)
% FREQUENCY OF DIRECTION
YELLOWKNIFE

LEGEND

WMS — WIND MEAN SPEED (M.P.H.)

(3) REPRESENTS % CALM

JANUARY WMS - 8.4



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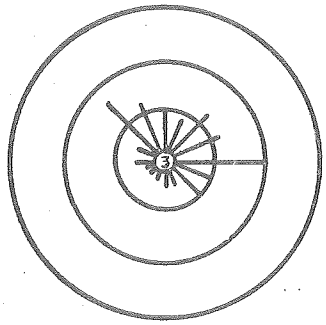
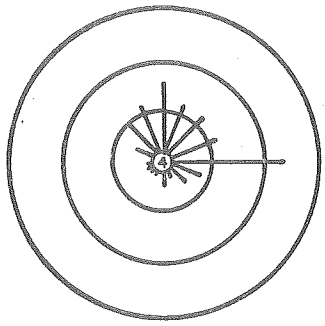
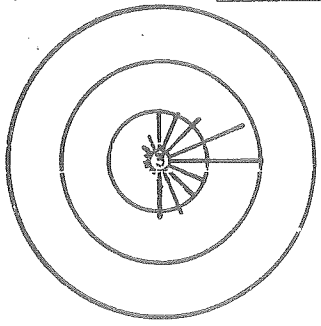


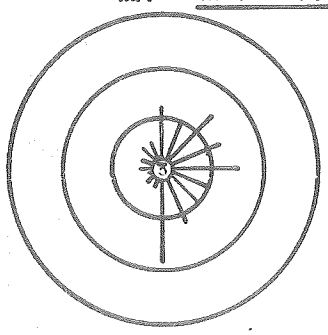
MARCH WMS — 9.0



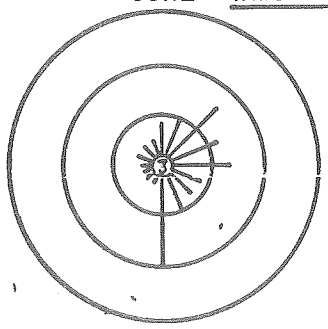
APRIL WMS — 10.0



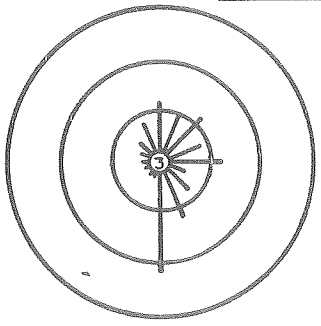
MAY WMS - 10.4



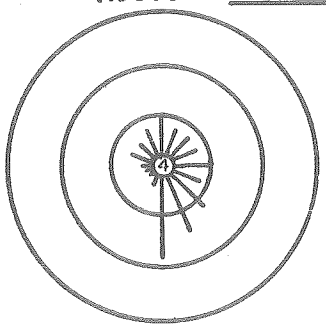
JUNE WMS - 10.7



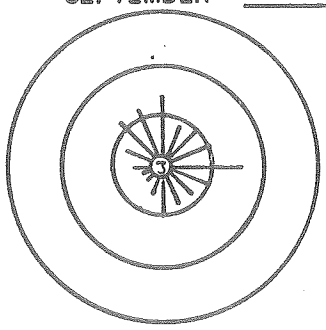
JULY WMS - 10.0



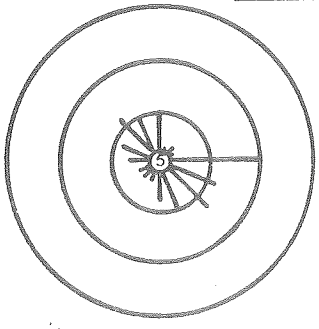
AUGUST WMS - 9.9



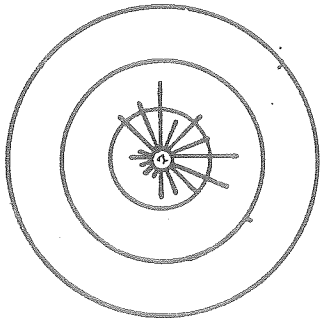
SEPTEMBER WMS - 10.3



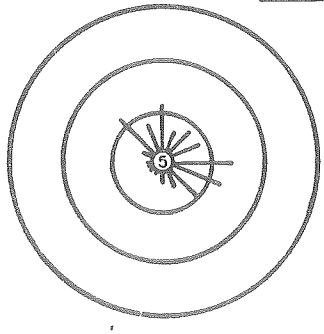
OCTOBER WMS - 9.8



NOVEMBER WMS - 9.4



DECEMBER WMS - 7.9



APPENDIX V

BRIEF DESCRIPTION OF THE HIGH VOLUME SAMPLER LOCATIONS

LOCATION OF HI-VOL SAMPLING STATION

Hi-Vol Station Identification	Abbreviation Used	Height of Sampling Head Above Ground Level (in feet)	Location	
			Degrees from North	Distance from Giant Mine (miles)
Radio Tower	RT	14	245	4.1
Airport*	Air*	35	230	3.5
Northland Trailer Park	NT	14	198	4.3
Defence Headquarters*	NRHQ*	14	190	3.3
Fisheries Warehouse	FW	14	174	2.7
Giant Trailer Park*	GT*	14	190	1.3
Giant West	GW	4	250	0.3
Giant North	GN	4	9	1.5
Hudson's Bay Store	NAPS	24	188	3.5

* Existing stations under Phases I and II of study.
Phase I of Study - March 12 - June 4, 1973.
Phase II of Study - April 21, 1974 - February 10, 1975.
Phase III of Study - February 11, 1975 - October, 1975.

Note: All nine stations formed part of the expanded network under Phase III of the study.

APPENDIX VI

SUSPENDED PARTICULATE SAMPLING PROGRAM - QUALITY ASSURANCE CHECKS

COMPARISON BETWEEN XRF AND COLORIMETRY

Filter Identification	Date of Sampling	X-Ray Flourescence by NEC*		Vasak & Sedivec Colorimetry by EPS		Difference in Arsenic Concentrations	% Discrepancy
		Date of Analysis	Arsenic Concentration (ug/m^3)	Date of Analysis	Arsenic Concentration (ug/m^3)		
13	24/05/75	3-7 /07/75	0.47	19-21/01/76	0.34	0.13	28
56	11/06/75	3-7	0.64	19-21	0.39	0.25	39
81	20	3-7	0.68	19-21	0.53	0.15	22
82	20	3-7	0.61	19-21	0.53	0.08	13
90	23	3-7	0.57	19-21	0.41	0.16	28
98	26	3-7	1.82	19-21	1.60	0.22	12
115	17/07/75	7-11/08/75	0.12	13-16/01/76	0.11	0.01	8
124	5	7-11	0.43	19-21/01/76	0.33	0.10	23
128	8	7-11	0.53	13-16/01/76	0.46	0.07	13
131	8	7-11	0.52	19-21/01/76	0.51	0.01	2
149	14	7-11	0.86	19-21	0.62	0.24	28
168	17	7-11	0.19	13-16/01/76	0.18	0.01	5
209	1/08/75	16-20/10/76	1.38	13-16	1.16	0.22	16
269	22	16-20	0.50	19-21/01/76	0.45	0.05	10
292	31	16-20	0.58	19-21	0.44	0.14	24
356	27/09/75	16-20	0.57	13-16/01/76	0.40	0.13	23
379	3/10/75	24-27/10/75	3.91	13-16	3.23	0.68	18

* NEC - Northern Environmental Consultants, Edmonton.
** EPS - EPS Regional Laboratory, Edmonton.

Avg. deviation ± 17%.

TOTAL ARSENIC TESTS - PARTICULATE AND VAPOUR BY CHEMICAL IMPREGNATION OF HIGH VOLUME FILTERS

Filter Identification	Date of Sampling	Station ID	Arsenic Analysis* (ug/m^3)		Total Filter System
			Normal Filter	Treated Filter	
157	9/07/75	GN	0.19	0.04	0.23
158	9	GW	0.09	0.02	0.11
159	9	GT	0.03	<0.01	0.03
160	9	AIR	0.01	<0.01	0.01
234	10/08/75	GT	<0.01	<0.01	<0.01
235	10	GW	0.02	<0.01	0.02
236	10	GN	0.23	0.04	0.27
430	21/10/75	GW	<0.01	<0.01	<0.01
431	21	GN	0.01	<0.01	0.01
437	24/10/75	GT	<0.01	<0.01	<0.01
438	24	GW	0.17	<0.01	0.17
447	27/10/75	GT	0.24	<0.01	0.24
449	27	GN	<0.01	<0.01	<0.01
456	30/10/75	GT	0.02	<0.01	0.02
457	30	GW	0.33	<0.01	0.33
458	30	GN	<0.01	<0.01	<0.01

* Note: 24 hour sampling period.

PERCENTAGE ERROR

High Volume Sampler Operation	± 5%
- per 24 hour sampling period	
- per Hi-Vol sampler flowrate range - 30 to 50 cfm	
Laboratory Analysis for:	
- Total Suspended Particulate levels	± 5%
- Arsenic Concentrations in Ambient Air	
- Vasak and Sedevic (pyridine) colorimetric method performed by EPS Regional Laboratory Edmonton	±15%
- X-ray Fluorescence performed by:	
- Northern Environmental Consultants	±15%
- Chemistry Division, Ottawa	±15%
- Lead Concentrations in Ambient Air by XRF	±15%
Overall Concentration expressed as:	
- Total Suspended Particulates (ug/m^3)	±10%
- Arsenic Concentration ($ug\ As/m^3$)	±20%
- Lead Concentration ($ug\ Pb/m^3$)	±20%

APPENDIX VII

METEOROLOGICAL DATA FOR ARSENIC CONCENTRATIONS GREATER THAN 0.5 ug As/m^3

METEOROLOGICAL DATA FOR ARSENIC CONCENTRATIONS IN EXCESS OF 0.5 MICROGRAMS PER CUBIC METER

Filter Identification	8556	8583	8587
TSP (ug/m^3)*	9	38	60
As (ug As/m^3)**	0.95	0.62	0.70
Location	GT	GT	GT
Date Of Sampling	27/3/73	5/4/73	7/4/73
Sampling Time (hours)	24	24	24
Wind			
i. Direction	NE	NE	NE SE
ii. Frequency	80%	80%	50% 30%
iii. Speed (mph)			
a. High	11	18	12
b. Low	3	8	3
c. Predominate	7 ± 2	15 ± 3	6 ± 2
Temperature (^oF)			
i. High	27	15	18
ii. Low	-2	-4	-10
Cloud Cover	Overcast	Cloudy	Clear

* TSP = Total Suspended Particulates
** As = Arsenic Concentration in Ambient Air

METEOROLOGICAL DATA FOR ARSENIC CONCENTRATIONS IN EXCESS OF 0.5 MICROGRAMS PER CUBIC METER

Filter Identification	3017	6	60	61	64	73	76	83
TSP (ug/m^3) *	19	32/32/32	11	65	14	7	3	13
As (ug As/m^3)**	0.68	1.34	0.54	1.68	1.11	0.65	0.98	0.52
Location	GT	GT	NRHQ	GT	GT	GT	GT	AIR
Date of Sampling	9/5/74	27/28/29 5/74	21/11/74	21/11/74	25/11/74	3/12/74	5/12/74	10/12/74
Sampling Time (hours)	24	72	24	24	24	24	24	24
Wind								
i. Direction	N W NW	N N N	NW NE	NW NE	N	N	NE	NE
ii. Frequency (%)	60 15 25	80 80 80	30 70	30 70	80	85	80	85
iii. Speed (mph)								
a. High	8	25 23 19	10	10	17	11	22	17
b. Low	2	18 12 4	6	6	8	5	8	3
c. Predominate	5 ± 2	20 ± 5	7 ± 2	7 ± 2	12 ± 3	7 ± 2	15 ± 3	10 ± 3
Temperature (^{o}F)								
i. High	47	38 33 46	3	3	13	4	1	-11
ii. Low	34	30 27 32	-9	-9	6	1	-10	-29
Cloud Cover	Overcast	Cloudy	Cloudy	Cloudy	Overcast	Overcast	Overcast	Cloudy

* TSP = Total Suspended Particulates
** As = Arsenic Concentration in Ambient Air

METEOROLOGICAL DATA FOR ARSENIC CONCENTRATIONS IN EXCESS OF 0.5 MICROGRAMS PER CUBIC METER

Filter Identification	102	121	142	143	146	171
TSP (ug /m^3)*	11	9	7	11	20	26
As (ug As/m^3)**	1.50	0.59	1.36	1.03	3.16	1.40
Location	AIR	NRHQ	AIR	GT	GT	AIR
Date of Sampling	23/01/75	10/02/75	3/03/75	3/03/75	5/03/75	4/04/75
Sampling Time (Hours)	24	24	24	24	24	24
Wind						
i. Direction	NE	N	N NE	N NE	N	NE
ii. Frequency (%)	80	80	40 50	40 50	80	25
iii. Speed (mph)						
a. High	12	10	10	10	20	10
b. Low	8	5	4	4	calm	calm
c. Predominate	10 ± 2	9 ± 2	7 ± 2	7 ± 2	15 ± 3	5 ± 2
Temperature (^oF)						
i. high	-13	-31	14	14	5	-5
ii. Low	-28	-42	-6	-6	-24	-22
Cloud Cover	Overcast	Cloudy	Cloudy	Cloudy	Cloudy	Cloudy

* TSP = Total Suspended Particulates
** As = Arsenic Concentration in Ambient Air

METEOROLOGICAL DATA FOR ARSENIC CONCENTRATIONS IN EXCESS OF 0.5 MICROGRAMS PER CUBIC METER

Filter Identification	56	81	82	90	98	93	128	131
TSP (ug/m^3)*	296	232	37	185	121	106	130	622
As (ug As/m^3)**	0.64	0.68	0.61	0.57	1.82	0.62	0.53	0.52
Location	GW	GW	GN	GW	GW	AIR	NT	GT
Date of Sampling	11/06/75	20/06/75	20/06/75	23/06/75	26/06/75	26/06/75	8/07/75	8/07/75
Sampling Time (Hours)	24	24	24	24	24	24	24	24
Wind								
i. Direction	E Calm	E S	S E	E SE	E NE	NE E	N	N
ii. Frequency (%)	20 35	20 30	30 20	40 40	30 65	65 30	60	60
iii. Speed (mph)								
a. High	12	10	10	3	20	20	13	13
b. Low	25	2	2	5	5	5	1	1
c. Predominate	5 ± 2	5 ± 2	5 ± 2	5 ± 3	15 ± 5	15 ± 5	5 ± 2	5 ± 2
Temperature (^oF)								
i. High	19	23	23	23	26	26	26	26
ii. Low	11	10	10	12	19	19	12	12
Cloud Cover	Cloudy	Cloudy	Cloudy	Cloudy	Cloudy	Cloudy	Cloudy	Cloudy

* TSP = Total Suspended Particulates
** As = Arsenic Concentration in Ambient Air

METEOROLOGICAL DATA FOR ARSENIC CONCENTRATIONS IN EXCESS OF 0.5 MICROGRAMS PER CUBIC METER

Filter Identification	149	209	269	292	356	379	413
TSP (ug/m^3)*	123	99	82	20	25	21	7
As (ug As/m^3)**	0.86	1.38	0.50	0.58	0.57	3.91	1.61
Location	GW	GW	GW	GT	AIR	GW	GW
Date of Sampling	14/07/75	1/08/75	22/08/75	31/08/75	27/09/75	3/10/75	15/10/75
Sampling Time (Hours)	24	24	24	24	24	24	24
Wind							
i. Direction	E	SE	E NE	N S	NE	E	E N NE
ii. Frequency (%)	60	80	45 45	25 45	85	85	20 40 35
iii. Speed (mph)							
a. High	13	15	12	15	10	16	10
b. Low	0	4	5	1	2	5	3
c. Predominate	9 ± 3	9 ± 4	7 ± 2	8 ± 2	7 ± 2	13 ± 3	5 ± 2
Temperature (^oF)							
i. High	68	21	21	10	1	7	0
ii. Low	55	13	8	4	-1	2	-2
Cloud Cover	Cloudy	Cloudy	Cloudy	Cloudy	Cloudy	Cloudy	Cloudy

* TSP = Total Suspended Particulates
** As = Arsenic Concentration in Ambient Air

APPENDIX VIII

BRIEF DESCRIPTION OF DEPOSITION SAMPLING SITE LOCATION

DESCRIPTION ON DUSTFALL STATIONS

Station Identification	Type of Field	Container Opening Height Above Ground Level (in feet)	General Comments on Site Location
D1	Stand	13	On Detah elementary school roof.
D2	Pole	6	100 ft. west of Con Mine ducking area, on rocky out-crop.
D3	Stand	14	On mobile trailer home in Northland Trailer Park, 50 feet from NT High-volume sampler.
D4	Stand	17	On hospital roof.
D5	Stand	22	On Hudson Bay Store roof, 50 feet from NAPS High-volume sampler.
D6	Pole	6	300 feet east of paved roadway near Niven Lake.
D7	Pole	10	In Back Bay area, 10 feet from shoreline on rocky out-crop.
D8	Stand	30	On airport terminal building, 50 feet from AIR, High-volume sampler.
D9	Pole	7	300 feet east of MOT radio tower.
D10	Stand	4	2,000 feet north off gravel roadway, 10 miles west of Giant Mine, serves as background station.
D11	Stand	15	On mobile trailer home in housing quarters of Giant Mine employees, 50 feet from GT High-volume sampler.
D12	Pole	11	25 feet east of shoreline on the tip of Latham Island.
D13	Stand	4	300 feet west of gravel road to Detah on rock mound near clearing.
D14	Pole	6	1,000 feet east of Giant's open pit mining operations on leeward side of hill, 150 feet from paved roadway.

DESCRIPTION ON DUSTFALL STATIONS - CONTINUED

Station Identification	Type of Field	Container Opening Height Above Ground Level (in feet)	General Comments on Site Location
D15	Pole	6	1/3 mile directly west of Giant Mine stack on rocky ridge, ½ mile north of open pit mining operations, 300 feet from GW High-volume sampler.
D16	Pole	6	300 feet off gravel roadway intersection, ½ mile north of Giant.
D17	Stand	4	300 feet off gravel roadway on rock mound clearing, 1 mile north of Giant.
D18	Stand	4	300 feet south of road and elevated 100 feet above lake level.
D19	Stand	4	300 feet from paved road north of Stack Lake on rock mound 50 feet above road level.
D20	Stand	4	1,000 feet south of gravel roadway, 10 miles east of Giant Mine, serves as second background station.
D21	Stand	4	Adjacent to fenced in As_2O_3 tailings pond and between Negus tailings pile and Con Mine operations, on rocky mound.
D22	Pole	4	On sparsely vegetated ridge halfway between Con Mine operations and new city housing subdivision.

APPENDIX IX

QUALITY CHECK ON LABORATORY PROCEDURE FOR DEPOSITION RATE SAMPLES

QUALITY CHECK ON LABORATORY PROCEDURE FOR DEPOSITION RATE OF SAMPLES

Identification	Weight of Standard Dust Sample (mg)	Calculated Total Deposition Rate - (30 Days) (Tons/sq.-Mi/Month)	Gravimetric Analysis of Standard Dust Sample			Arsenic Analysis of Dried Dust Sample		% Recovery for Total Dust Sample
			Insoluble (mg)	Soluble (mg)	Total (mg)	Wt. of Arsenic (ug)	Arsenic Content (%)	
1	89	13.9	77	5	82	39	0.050	92
2	184	28.8	159	17	176	81	0.045	96
3	214	33.5	205	8	213	108	0.050	100
4	443	69.3	433	11	444	205	0.050	100
5	<1	Distilled Water Blank	1	1	2	-	--	Not Applicable
6	86	13.5	69	5	74	41	0.055	86
7	121	18.9	116	4	120	68	0.055	99
8	353	55.2	347	9	356	205	0.055	100

Note Samples #1 to 4 dried at 105 ^{o} C overnight (10 hours)
Samples #6 to 8 dried at 25 ^{o} C for 72 hours

* Calculation (in tons/sq mi/month) = $\frac{\text{weight (in mg) x 0.1565 x 30 days}}{\text{\# of days exposed}}$

Σ % recovery	674
# of analysis	7
Average % Recovery	96%

APPENDIX X

TOTAL PARTICULATE AND ARSENIC DEPOSITION RATES

(June - October 1975)

TOTAL PARTICULATE DEPOSITION RATE
(Tons/Sq Mi/Month)

Month	June	July	August	September	October
Station					
D1	5.81	9.24	5.11	6.26	2.93
D2	4.92	39.9	SL	0.63	7.65
D3	9.88	9.34	10.1	11.2	4.57
D4	9.13	7.19	9.49	4.76	3.23
D5	19.7	43.2	19.3	12.3	13.0
D6	5.21	6.81	8.80	5.59	1.39
D7	9.95	10.4	11.4	4.84	1.42
D8	16.2	15.9	14.6	3.64	9.87
D9	3.05	3.09	5.30	1.85	0.54
D10	4.49	21.4	8.23	3.77	0.77
D11	9.83	14.4	5.06	5.20	2.71
D12	5.30	9.57	7.30	14.7	1.97
D13	4.07	7.17	2.76	2.45	0.41
D14	12.4	45.2	27.9	20.6	10.3
D15	205	5.68	8.92	3.44	3.32
D16	11.6	34.7	30.6	20.1	2.32
D17	5.50	45.0	4.16	3.61	0.75
D18	4.52	13.0	2.65	2.52	1.23
D19	4.20	SL	SL	2.83	1.13
D20	15.6	9.55	3.23	14.9	0.83
D21	33.6	6.10	2.83	1.98	2.08
D22	3.04	11.7	3.87	3.58	1.99

*SL - Sample Lost

ARSENIC DEPOSITION RATE
(Pounds/Sq Mi/Month)

Month	June	July	August	September	October
Station					
D1	2.95	4.47	1.84	2.13	1.67
D2	4.74	5.50	SL	16.7	5.55
D3	1.55	5.67	4.09	5.69	6.85
D4	2.86	3.82	2.52	4.83	1.05
D5	3.93	9.67	14.2	5.84	3.84
D6	2.52	5.13	3.86	6.63	0.12
D7	1.61	5.15	5.73	4.01	2.11
D8	3.23	6.85	4.96	3.07	3.84
D9	1.30	1.98	4.76	0.65	2.28
D10	0.21	3.72	9.76	0.57	1.38
D11	3.34	9.00	9.15	10.2	3.90
D12	3.38	7.91	5.21	1.61	3.39
D13	0.21	5.96	2.82	0.86	2.67
D14	16.0	34.7	37.2	35.4	13.3
D15	58.1	15.4	52.0	8.12	26.1
D16	22.3	42.7	88.2	21.2	12.8
D17	6.93	16.1	14.3	5.46	4.31
D18	5.90	18.2	5.13	5.86	3.01
D19	2.96	SL	SL	5.38	4.91
D20	4.78	2.27	2.50	4.61	2.53
D21	150	9.13	3.19	3.32	3.78
D22	2.10	4.05	3.15	2.20	2.87

*SL - Sample Lost

APPENDIX XI

GENERAL DESCRIPTION OF SO_2 MONITOR SITE LOCATIONS

GENERAL DESCRIPTION OF SO_2 MONITOR SITE LOCATIONS

Station Identification Location	Hudson's Bay Store (HB)	EPS Warehouse (WARE)	Super Crest Buildings (SUPER)
Direction	S	SSE	N
Degrees*	188	165	009
Distance (miles)*	3.5	3.0	1.5
Height above ground of sampling head (feet)	25	30	30
Period of operation	April/73-Oct/75	June/75-Oct/75	June/75-Oct/75

*Degrees and distance from Giant Mines stack in clockwise direction from true north.

APPENDIX XII

METEOROLOGICAL CORRELATION OF SO_2 CONCENTRATION GREATER THAN 0.17 PPM (1973 - 1975)

METEOROLOGICAL CORRELATION FOR SO_2

CONCENTRATION GREATER THAN 0.17 PPM

YEAR 1973

Station Designation	Month	Day	Time of Day	Average Hourly Concentration (ppm)	Wind Correlation	
					Direction	Speed (mph)
HB	April	13	4-5	0.20	N	6
HB	April	13	9-10	0.18	NE	7
HB	April	14	21-22	0.19	NNE	3
HB	Sept.	4	3-4	0.18	NNE	13
HB	Sept.	10	20-21	0.25	NNE	5

METEOROLOGICAL CORRELATION FOR SO_2

CONCENTRATION GREATER THAN 0.17 PPM

YEAR 1974

Station Designation	Month	Day	Time of Day	Average Hourly Concentration (ppm)	Wind Correlation	
					Direction	Speed (mph)
HB	April	10	21-22	0.21	N	7
HB	April	23	9 - 10	0.19	NNW	8
HB	June	17	12-13	0.17	ENE	5
HB	Aug.	20	21-22	0.36	NNW	7
HB	Aug.	20	22-23	0.30	NNW	7
HB	Aug.	22	23-24	0.22	N	7
HB	Aug.	23	0-1	0.28	NNE	5
HB	Aug.	30	20-21	0.42	N	4
HB	Oct.	11	9-10	0.17	NE	2
HB	Oct.	17	22-23	0.24	W	4
HB	Oct.	27	6-7	0.21	NNW	5
HB	Nov.	6	2-3	0.19	N	13
HB	Nov.	2	14-15	0.30	N	7
HB	Nov.	30	16-17	0.19	N	4
HB	Dec.	20	16-17	0.17	NNW	2

METEOROLOGICAL CORRELATION FOR SO_2

CONCENTRATION GREATER THAN 0.17 PPM

YEAR 1975

Station Designation	Month	Day	Time of Day	Average Hourly Concentration (ppm)	Wind Correlation	
					Direction	Speed (mph)
HB	Jan.	26	14-15	0.17	N	4
HB	Feb.	20	16-17	0.19	NNE	7
SUPER	June	17	17-18	0.20	E	6
SUPER	June	24	20-21	0.25	SSE	6
SUPER	June	24	21-22	0.25	S	5
SUPER	June	28	12-13	0.19	NE	6
SUPER	June	28	13-14	0.23	ENE	14
SUPER	June	28	14-15	0.21	ENE	16
SUPER	June	28	15-16	0.19	ESE	14
SUPER	June	28	16-17	0.18	E	9
SUPER	June	28	17-18	0.18	E	8
SUPER	June	28	18-19	0.18	NE	7
SUPER	June	28	19-20	0.17	NNE	9
SUPER	June	28	20-21	0.17	NE	5
SUPER	July	10	18-19	0.23	S	9
SUPER	July	10	19-20	0.17	SSW	9
SUPER	July	10	20-21	0.25	S	9
SUPER	July	20	20-21	0.34	S	9
SUPER	July	20	22-23	0.20	S	5
HB	Aug.	31	0-1	0.27	N	9
HB	Aug.	31	2-3	0.27	N	10
SUPER	Aug.	14	15-16	0.17	SSW	5
SUPER	Aug.	27	6-7	0.26	S	9
WARE	Aug.	9	5-6	0.23	NNW	2
WARE	Aug.	9	6-7	0.18	NNW	4
WARE	Aug.	23	19-20	0.17	NNW	4
WARE	Aug.	23	20-21	0.25	NNW	7
WARE	Aug.	23	21-22	0.25	NNW	6
WARE	Aug.	31	3-4	0.20	N	8