WATER POLLUTION

YELLOWKNIFE BAY

NORTHWEST TERRITORIES

JAN 3 1964

Prepared By

Department of National Health & Welfare
Public Health Engineering Division
541 Federal Public Building
Edmonton, Alberta

This report contains recommendations regarding the disposal of sewage and arsenic-containing wastes into Yellowknife Bay.

December 23, 1963

J.W. Grainge, M.S., P. Eng.
District Engineer

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CLASSIFICATIO

TO
A
Dr. P.E. Moore,
Medical Services.

YOUR FILE No.
Votre dossier
850-5-X75

OUR FILE No.
Notre dossier
368-1-Y2

FROM
De
Chief - Public Health
Engineering Division, Ottawa

DATE Jan. 13, 1964

FOLD

SUBJECT
Sujet
Arsenic in Water - Yellowknife Bay, N.W.T.

Resources

We are pleased to forward to you a copy of a report concerning Water Pollution, Yellowknife Bay, N.W.T., prepared by our Mr. Grainge, subsequent to a study made during July 1963. This investigation was carried out in order to ascertain information on the current behaviour in Yellowknife Bay with respect to arsenic waste discharged into this bay via Baker Creek by Giant Mines.

A copy of this report has been forwarded to Mr. Christie, Chief Mining Engineer, Resources Division, Department of Northern Affairs & National Resources. We trust that through him efforts will be made by the industry to implement the conclusions outlined in this report.

As you know, we intend to maintain close surveillance over the arsenic concentration levels in Yellowknife Bay through a working arrangement with the Resources Division of Northern Affairs. Copies of this report are being forwarded to Dr. K.F. Butler of your Directorate at Edmonton, for local distribution.

W R Edmonds
W.R. Edmonds, P.Eng.

WRE/jc

Enc.

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SUMMARY

This report is primarily a study of the disposal of sanitary sewage and arsenic-containing mill wastes into Yellowknife Bay in relation to the water supplies in the vicinity. It includes a report on a search of literature on the subject of the physiological effects of arsenic in drinking water.

Main Conclusions

1. There should be local standards for the arsenic content of drinking water.

Suggested desirable level, which should be attainable eventually.	0.01 mg/l[*]
Emergency level. Frequent excess of this demands further study and new control methods.	0.05 mg/l
Emergency level. Excess of this demands immediate distribution of a substitute drinking water supply by truck.	0.30 mg/l

2. Samples of water for arsenic analyses should be taken weekly during May and June, and monthly during the remainder of the year. Whenever the arsenic content exceeds 0.1 mg/l, daily samples from that particular source should be taken and tested.

3. The effluent from Bow Lake should be discharged at "the Narrows", in summer.

4. Giant Mines should increase the size of the tailings pond to the maximum possible volume in order to increase the amount of precipitation of the arsenic trioxide by flocculation with the ferric hydroxide contained in the tailings.

5. In order to keep the bacterial load in Yellowknife Bay as low as possible, the new subdivisions in Yellowknife should be planned so that as much sewage as possible is discharged into Pud Lake.

OBJECTIVES OF INVESTIGATION

1. To determine if there would be worthwhile advantage in discharging effluent from the Giant Mines[**] mill tailings and sewage pond to the Narrows by the simple expedient of improving and raising dams on the outlet of that pond (Bow Lake), which usually discharges into Baker Creek. See maps, Appendix J.

2. To determine if there would be value in varying the discharge from Bow Lake during the year.

3. To determine if there would be value in extending the water intake pipeline for Giant Mines a considerable distance into Yellowknife Bay in order to be farther from the mouth of Baker Creek.

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[*] See abbreviations, Appendix A.

[**] Giant Yellowknife Mines Ltd.

4. To determine if there would be sufficient value to warrant the filling-in of the narrow channel between Latham Island and the peninsula.

5. To determine if there are currents within Yellowknife Bay which would be suitable either for obtaining water free from arsenic and sewage pollution, or for disposing of arsenic wastes and sewage pond effluent so that it might be carried into Great Slave Lake without contaminating existing water supplies.

6. To make recommendations for (1) standards of arsenic content in the drinking water in this community, and (2) emergency measures in the event of those standards being exceeded.

INTRODUCTION

Yellowknife is situated 600 miles north of Edmonton, on the north side of the north arm of Great Slave Lake, on the west shore of Yellowknife Bay which is the mouth of Yellowknife River. The population is 4300, including 100 Indians.

The settlement began with the development of Con and Negus Mines* in 1937-8, and for many years it remained a gold mining town and supply center for other mines and prospecting in the surrounding region. It has retained this initial role and also become a government administrative center by virtue of its urban amenities and transportation facilities. The latter includes having a good all weather airport, road contact with Edmonton and being headquarters for a half a dozen aircraft charter flight companies.

In 1948-9 the "New Town" was created by the expedient of constructing water supply and sewerage systems on a moss-covered sandy flat land. Most businesses and residences have moved to this area, but many people remain in the "Old Town" on the peninsula and Latham Island. The company settlements of Giant Yellowknife Mines, 2½ miles north of the new townsite, and Con Mine, ½ mile south have piped water supply and sewerage systems. See details in Appendix B.

The Yellowknife River which flows into Yellowknife Bay from the north has a very low mineral content. The flow varies usually from 600 to 1500 cfs. See Appendix D for further data. There are seasonal and annual fluctuations in the lake level of up to 3 ft., and winds produce a maximum variation of almost a foot.

Liquid mine wastes from Giant Mines, containing arsenic** from the gold ore, are pumped into Bow Lake which empties into Baker Creek and eventually to

* Negus Mine discontinued operations approximately 1953.

** Arsenic trioxide (As_2O_3) with traces of arsenic pentoxide (As_2O_5).

Yellowknife Bay. This arsenic contamination, to a greater or lesser degree, of the drinking water for the people in the area, is physiologically harmful. See Appendix I.

Sewage ponding (lagooning) is standard treatment for all three sewerage systems in the area. The effluent from the main townsite sewage pond discharges into a backwater bay within Yellowknife Bay at a point one mile upstream from where 15 people living on Joliffe Island obtain their drinking water. This point is also 2 miles and 2.7 miles, respectively, upstream from the water intakes of the New Town and Con Mine water supplies.

There are one or two places in the old townsite where septic tank effluent and raw sewage are discharged directly into the bay. The sewage from the residences, offices, mills, etc. of Giant Mines (population 360), is comminuted and discharged with the mill wastes into Bow Lake.

When the lake and bay are ice free, which is from mid-May to late October, the wind has a significant effect on the movement of water in Great Slave Lake by producing water currents within Yellowknife Bay.

In summer the wind is generally blowing 8 to 20 mph., average 10½ mph., and it is calm less than ½% of the time. There isn't a prevailing wind direction, however, it blows much more frequently N, NE, E, SE and S than it does NW, W and SW. See Appendix E.

STUDY OF AERIAL PHOTOGRAPHS AND SOUNDINGS

The aerial photos of the north end of the bay were studied and some soundings taken to determine the continuous water currents in the bay. The information showed that there is a single current, approximately 30 ft. wide, which cuts close to the west shore just prior to the Narrows and swings over to the east shore at the Narrows. It continues past the west bank of a point of land jutting into the bay on the east shore. See Dwg. #4, Appendix J.

The wide mud flats along the west shore of the bay from the Narrows to within 1,000 ft. of the mouth of Baker Creek are evidence of the fact that there is often still water with no scouring currents in this vicinity.

1946 SURVEY

In 1946 a survey, with similar objectives in mind, was made by this office. It was part of a sanitary engineering survey for the proposed "New Town".

Water currents in the bay west of Latham Island (Back Bay) were studied by observing the movement of floating markers. Cedar poles 6 ft. long, 2½ inches in diameter were weighted with lead at one end so that they floated upright with 15 inches of the pole above water.

The study, as shown in Drawing No. 1, Appendix J, indicates that on the particular times of the experiments the water currents were (1) south 782 ft./hr. (0.15 mph.) when the wind was north at 10 mph., and (2) north at 277 ft./hr. (0.05 mph.) when the wind was south at 10 mph., after deducting 18 ft./hr., which is the calculated component of the velocity due to the force of the wind on the exposed parts of the poles.

Assuming that the water current is contained in the upper 5 ft. of water and in the middle 2,000 ft. (the total width of the water body is 2,650 ft. at this cross-section and the mid depth is 26 ft.), the current flow is 770 cfs. northward and 2,170 cfs. southward. The maximum flow rate through the water channel between Latham Island and the mainland (14 sq. ft. cross-section) has been observed at 13 cfs. which is negligible by comparison. Therefore, there must be deep reverse water currents in this bay.

DESCRIPTION OF WATER CURRENT STUDY

Rhodamine B dye powder was discharged from paper bags onto the lake surface, from the back of a motor boat, at times and places as shown on Drawing No.'s 2 and 3, Appendix J.

Discharge Points

1. The Narrows, near the mouth of Yellowknife River, a proposed discharge point for effluent from Bow Lake, the mill tailings pond of Giant Mines.

2. The mouth of Baker Creek, the existing discharge point of effluent from Bow Lake.

3. The existing point of discharge of effluent from the sewage pond of the main townsite of Yellowknife.

The movement of the dye in the bay was observed from an airplane at various intervals thereafter. Forty color photographs were taken, from which slides were made. Prints were made from four of these to illustrate points under discussion. Rough sketches were drawn while in flight and reproduced in Drawing No.'s 2 and 3, Appendix J. The dye movement velocity was calculated and compared with the average river flow velocity on the same drawings.

The river flow rate was determined from hydrological records of the flow in the main branch of the river, plus 12% of the average flow for the month of July, which is approximately the flow in Cameron River, a branch of the Yellowknife River. See Appendix D.

OBSERVATIONS OF DYE TRACER MOVEMENT

July 15 - 16

On July 15, 1963 10 lb. of dye was deposited at the "Narrows", near a proposed outfall point for effluent from Bow Lake. The dyed water moved out into the main stream in ½ hour and thence into the bay.

Observations were made 50 min. after depositing the dye and it seemed that the body of dyed water was splitting apart, with approximately one-half getting into the main stream. See Photo No. 1. Appendix I. A northwest wind was blowing at 10 mph. and was apparently carrying the dye, which was found to be mainly in the upper two feet of the water, out into the main stream and it became too dilute to be recognizable.

Observations 4 hr. and 15 min. after depositing dye showed that the visible dye front had moved south 1360 ft. at a rate of less than a third of the average water flow rate in the bay. The dye color was much weaker, and it is likely that much of the dyed water as observed after 50 min. had moved out into a main stream (not otherwise noticeable as a main stream). See Photo No. 2. Appendix I.

Some of the increased dilution of dye may have resulted from dyed water mixing to deeper depths. This point couldn't be checked by examining samples of water, because the dye was too dilute to be observed in nessler tubes. This effect wasn't great because the water is very shallow in the region of concern.

The minimum dilution at which dye can be distinguished in water contained in nessler tubes is in the order of 0.1 mg/l. A calculation based on the assumption that the dye remained in the top 2 ft. of water, which was the case in a similar situation on July 17, shows that this is approximately the dilution as illustrated in Photo No. 1, Appendix I.

Observations 7 hr. and 30 min. after depositing the dye showed that the visible dye front had moved 1,000 ft. farther south and a little west. The southward movement was approximately half the average southward water flow rate. During this time the wind veered gradually to the southwest.

Observations 9 hr. and 40 min. after depositing the dye showed that the visible dye front had moved 750 ft. farther south and a little farther west. The southward movement was approximately half the average southward water flow rate. The wind, blowing at 9 to 10 mph., had veered to south-southwest.

Observations 18 hr. and 20 min. after depositing the dye showed that the visible dye front advanced southward 2475 ft. at the western edge but only 1500 ft. in the vicinity of the previous mid stream front. The southward movement at the western front of the dye was two-thirds the average southward water flow rate, after considering the fact that the south wind raised the water level in the lake a half foot. The wind was generally south, but also south-southwest and southwest and was usually 9 to 14 mph.

It is apparent that a water current was moving southward along the west shore. It is apparent that the south wind had a stronger effect on the water in the central and eastern part of the bay. The study provides no information as to whether there was a reverse current or not in the central and eastern parts of the bay. However, if there was one, it would be counterbalanced by a southward movement of water at depth.

The color of the water was very faint at this time and by the time of the next observation, 25 hr. and 10 min. after the dye discharge, only a little dye was visible near the shore. Assuming that a fifth of the original 10 lb. of dye remained and was contained in the top 5 ft. of water, the dilution was in the order of 0.005 mg/l.

Dye deposits at the mouth of Baker Creek and the outlet of the townsite sewage pond at this time indicated a counter-clockwise current in Back Bay (west of Latham Island). A northeast wind was blowing at 10 to 13 mph. and the water along the west shore was exposed to this wind.

July 17

On July 17, 1963 20 lb. of dye was deposited in mid-stream at the "Narrows". The wind was generally north at 2 to 6 mph. and the dyed water moved south at twice the calculated average water speed as observed at 3 hr. and 40 min. after depositing the dye. See Drawing No. 3. Appendix J.

During the next 2 hr. and 55 min., dyed water moved at an average rate more than 8 times the calculated average water movement rate. The wind was north to east half the time at 3 to 6 mph., was calm for an hour and moved to the southeast at 7 mph. for the last short period.

It is apparent that there was a wind-caused south-ward-flowing surface current throughout the bay, which would be counterbalanced by northward-flowing deep current. It was much stronger in the main bay where the water is deeper than it was closer to the narrows where the water is shallow.

The dye didn't move appreciably between the observations made 6 hr. and 35 min. and 9 hr. and 45 min. after the dye discharge. The wind blew from the south at 6 to 9 mph. during this time apparently holding the surface water steady and allowing the entire river flow to travel southwards at depth.

At the same time in Back Bay (west of Latham Island), the dye front moved northwest at approximately 1500 ft./hr. and this surface flow was undoubtedly counter-balanced by a deep southeastward flow. This is five times the flow rate observed in the 1946 survey, even though the wind blew 10 mph. at that time. This is an indication that the water current is much faster at a very shallow depth. Another possible explanation is that the floating poles used in the 1946 survey were closer to the west shore.

At the same time dye deposited at the mouth of Baker Creek was moving eastward, apparently in a surface current because there was a negligible flow in Baker Creek (less than 10 cfs.).

Comparison - Narrows - July 15 and 17

The dye was deposited in the fast-moving stream in the Narrows and it spread throughout the bay. This was quite different from the previous dye deposit at the western shore of the Narrows and apparently moved partly in a western slow-moving stream. In the second case the north and northeast winds weren't obstructed by hills whereas in the first case the northwest winds were obstructed by the hills along the western shore. See photos No.'s 2, 3 and 4.

CONCLUSIONS RE WATER CURRENTS

Wind-caused water currents in the bay generally exceed the average water flow rate and usually cause considerable mixing of the arsenic wastes into the water, resulting in greater dilution of arsenic wastes at water supply intakes. The circular currents caused by most winds produce much more mixing of the arsenic wastes into the main body of water, than do northwest winds which cause vertical circular currents.

In winter when the ice protects the water surface from the wind, there is much less mixing, but apparently this effect is more than offset by the increased sedimentation of the precipitating arsenic.

Southern winds produced a surface current in the vicinity of the mouth of Baker Creek, which would carry arsenic wastes from there to the intake of the water supply for Giant Mines.

Northerly winds, which are frequent, produce a counter-clockwise surface current in Back Bay, as well as a vertical current in the middle of the bay. This counter-clockwise current would carry a small part of the total effluent from the main townsite sewage pond through the channel and into the small neck of water between Joliffe Island and the mainland in less than ten hours.

CONCLUSIONS RE ARSENIC IN WATER SUPPLIES

In winter approximately 83 lb. of arsenic per day enter the bay by way of Baker Creek. In summer there is an additional 61 lb. of arsenic per day as a result of reprocessing of stored calcine. In spring and to a lesser extent during rains, an undetermined amount of arsenic is washed into the river with the melting snow and rain water.

A comparison of dilution and chemical content as shown in table C-1, shows that there is considerable precipitation of arsenic from the water in the bay. This is reasonable because in precipitation processes, the amount of precipitation varies with time, although the rate decreases.

TREATMENT OF DRINKING WATER TO REMOVE ARSENIC

Arsenic may be removed from drinking water by mixing it with lime $Ca(OH)$, allowing the precipitate to settle, recarbonizing the water (diffusing with carbon dioxide) and filtering it. This is in fact a combination of water softening with lime (removing carbonate or temporary hardness) and standard water treatment.

The cost of such treatment would be 75¢ to $1.25 per 1,000 gal., which is excessive because treatment other than chlorination (5¢ per 1,000 gal.) isn't otherwise required for the Yellowknife water supplies.

GENERAL CONCLUSIONS

1. The objective should be set to reduce arsenic levels in the drinking water to less than 0.01 mg/l, and to do whatever is reasonable in order to obtain the results.

2. There are no continuous water currents in Yellowknife Bay which would provide a source of contamination-free drinking water or would provide a suitable disposal stream for arsenic wastes or sewage.

3. Discharge of the effluent from Bow Lake upstream of the "Narrows" in Yellowknife Bay in summer, would produce several improvements.

   (a) It would eliminate short circuiting, during southerly winds, of the arsenic wastes from the mouth of Baker Creek to the intake of Giant Mines water supply.

   (b) It would provide greater mixing of the wastes in the lake water, thereby increasing the dilution of arsenic.

   (c) It would increase by two to ten days, depending upon the river flow rate and currents, the time between the discharge of arsenic wastes into the bay and their reaching the intake of the various water supplies. This would provide somewhat greater reduction of arsenic concentration due to precipitation, which is a function of time.

4. The best effluent discharge point in the "Narrows" is the area where the current cuts close to the west shore.

5. Piping the effluent a distance of 20 ft. offshore, to a scouring mid-current, would provide somewhat better mixing of the effluent. This might be considered necessary in order to prevent objectionable-appearing deposition, but this work is not warranted in order to provide greater arsenic dilution. If by the following year it is found that sediment from the effluent had deposited along the shore and was objectionable in appearance, then the necessary piping should be laid.

6. Reduction of the flow rate of effluent from Bow Lake during May and June would result in a corresponding reduction of arsenic content in the water where the arsenic in runoff water is high.. However, the maximum variation which could be obtained, without an expensive dam-building program, would be no more than 10% approximately. This is too little to be worthwhile.

7. Controlling the rate of discharge from Bow Lake to conform with certain wind effects would provide no benefits because the wind is so changeable with respect to the time taken for wastes to reach the water supply intakes.

8. The tailings pond, area 90 acres, should be as large as possible in order to allow the maximum sedimentation of arsenic, which is a function of both settlement time and pond surface area. A resurvey should be made two to three years from now to assure that the pond hasn't filled in to a point where the time factor is insufficient for satisfactory sedimentation.

9. A practical monitoring program would be to make arsenic analyses of samples of water from the three water supplies as follows:

(a) Once per week during May and June, when the arsenic spring runoff water augments the usual concentration.

(b) Once per month throughout the rest of the year.

(c) Once per day from any supply when a test exceeds 0.1 mg/l.

(d) In summer near the north tip of Latham Island, and from the mouth of Baker Creek.

(e) If a road is constructed to the tailings pond outfall point, then the effluent when the road is open. Otherwise, occasionally during the summer.

(f) Occasionally at the Indian village (on the opposite shore, 4 miles downstream).

10. The flow of water under the Latham Island bridge is very small by comparison with that which flows to the east of the island, because the cross-sectional area of this water channel is so small by comparison, 133,000 sq. ft. compared to 14 sq.ft. See Diagram No. 4, Appendix J.

However, two desirable effects during a north wind, which is frequent, could be obtained by filling in the neck of water between Latham Island and the mainland. It would (a) increase the sewage dilution in the drinking water of the 15 inhabitants on Joliffe Island and (b) reduce the bacterial concentration by increasing the time for the sewage to reach Joliffe Island by approximately 1/3 to 3 days.

11. The sewage load in Yellowknife Bay should be reduced in whatever ways are consistent with the expense involved. The purpose is to reduce the number of pathogenic bacteria in the drinking water of the 15 people on Joliffe Island. To a lesser extent this is important to the people living at Con Mine and in the main townsite where the water supplies are chlorinated. Occasionally, slugs of unchlorinated water are possible due to the failure of the chlorinators.

It is gratifying to know that as soon as it became apparent that benefit might be derived from Bow Lake being discharged to the Narrows rather than to Baker Creek, Mr. D.R. DeLaporte made plans for this division. He proceeded with work in this connection throughout the 1963 construction season.

ACKNOWLEDGMENTS

Sincere gratitude is expressed to:

the employee of Giant Yellowknife Mines Ltd., including Mr. D.R. DeLaporte, Manager, his predecessor, Mr. M.K. Pickard, Mr. G. Ekins, Mechanical Superintendent, and Mr. E.O. Foster, Research Metallurgist, for their considerable assistance in the field work and for reviewing this report and making suggestions;

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Dr. George W. Burke, Jr., Chief, Water Quality Criteria and Practice Section, Division of Water Supply and Pollution Control, Public Health Service, U.S.A. for his advice and for referring pertinent literature regarding the physiological aspects of arsenic assimilation.

J.W. Grainge

J.W. Grainge, P. Eng., M.S.
District Engineer

APPENDIX A

ABBREVIATIONS AND SYMBOLS

ppm - parts per million

mg/l - milligrams per liter, which is equivalent to parts per million

cfs - cubic feet per second (of water)

mph - miles per hour

- pound

tpd - tons per day

#pd - lb. per day

As - arsenic

As_2O_3 - arsenic trioxide

As_2O_5 - arsenic pentoxide

APPENDIX B

DETAILS OF WATER SUPPLY AND SEWERAGE SYSTEMS

Water Supply System, Main Town

The public system supplies chlorinated water to the new townsite, population 2850, and the old townsite, population 650. A system of buried water mains serves the new townsite throughout the year and a system of ground-surface mains serves the old townsite in summer. Drinking water from this public system is trucked to residents of the old townsite in winter.

The water is subject to bacteriological contamination by runoff from the settlement including Giant Mines, the new townsite and unsewered old townsite, and by the effluent from Bow Lake, which is the sewage and mill tailings pond of Giant Mines. It is subject to positive sewage contamination by the effluent from the sewage pond, which discharges 2 miles above the intake, as measured in the most direct line via the small water channel between Latham Island and the mainland. See Drawings No.'s 2,3 and 4, Appendix J. It is subject to sewage contamination by a few septic tanks serving residences in the old townsite.

A total of eighteen people on the west side of Yellowknife Bay use unchlorinated drinking water. Fifteen of these live on Joliffe Island, one lives near the outfall point of effluent from the sewage pond and two live on Latham Island just north of the bridge to the peninsula. Approximately 100 people live on the east shore of Yellowknife Bay where the water is relatively free of bacterial contamination.

Water Supply, Con Mine (population 340)

A water distribution system is contained in a system of above-ground utilidors which also contain sewers and steam pipes. These supply all residences, the office, mill and mine, with chlorinated water. The water intake is situated 0.7 miles downstream from the water intake of the Main Town, so that the water is subject to the same sources of bacterial contamination, but to a lesser degree.

Water Supply, Giant Yellowknife Mines (population 360

A water distribution system is contained in utilidors together with sewers and steam pipes. These supply all residences, the office, mill and mine with chlorinated water. The water intake is located on the lakeshore on the opposite side of the breakwater from the mouth of Baker Creek. The water is subject to contamination by Baker Creek which carries runoff from the settlement and effluent from Bow Lake, the sewage-mill tailings pond.

Sewage Disposal, Main Town

All sewage from the new townsite is comminuted and pumped into a 20-acre pond. When full, this pond provides a theoretical time retention of over two months and $\frac{3}{4}$-acres of surface area per 100 people. There is no public sewerage system for the old townsite, and most people live there in primitive conditions. A few residences are provided with septic tanks and some of these have sub-surface effluent disposal with varying degrees of percolation. Raw sewage from at least one residence runs directly into the bay.

Sewage Disposal, Con Mine

All sewage from Con Mine runs into a water-tight concrete septic tank from which the effluent is pumped with the mill tailings to a pond which flows to lakes which drain southward into Great Slave Lake.

Sewage Disposal, Giant Yellowknife Mines

All sewage from Giant Yellowknife Mines is comminuted and pumped with the mill tailings into Bow Lake. Bacterial reduction would result from the ponding (time not determined) and especially from their sedimentation by flocculation of the immense quantities of ferric hydroxide in the wastes.

APPENDIX C

ARSENIC IN WATER OF YELLOWKNIFE BAY

Arsenic in the water in Yellowknife Bay is principally in the form of arsenic trioxide (As_2O_3). The source is the gold ore. At Giant Mines the arsenic is contained mainly in the effluent from the mill tailings pond, which discharges into the bay via Baker Creek. A small amount is contained in the dilute mill wastes which are discharged directly to Baker Creek and in mine water (originally mill water used to repulp sand and pumped into abandoned shafts). A small amount of arsenic is contained in stack wastes from both Con and Giant Mines, and which settles on the land and is carried into the bay by rain and melting snow.

Mill Processes at Giant Mine

Giant Mines was brought into production in 1948 and has since advanced to the position of third largest producer of gold in Canada. It currently treats 1,050 tons of ore (0.78 oz. of gold per ton) per day which is intimately associated with a complex mixture of sulfides, especially arsenopyrite and pyrite. The ore being treated at the present time is approximately 1.9% arsenic.

The main milling process consists of floatation, roasting of floatation concentrate and cyanidation of the calcine. In the secondary process the roaster fumes are separated and treated separately. See steps as follows and flow sheet.

1. By a series of crushing, grinding and screening operations the rock ore is reduced to fine grains so that the sulfides which contain the gold, are exposed.

2. In a floatation process the sulfides are coated with xanthate, a dry alcohol, which prevents them from becoming wetted and allows them to attach to the bubbles in the froth and be floated off.

3. The auriferous sulfide concentrate produced which contains 4 oz. of gold per ton, 10% arsenic and water (990 tpd.) is dewatered on a revolving cloth filter; and the water (900 tpd.), which contains arsenic (1.6 #pd.) is discharged directly to Baker Creek.

4. The dewatered concentrate (175 tpd.) is roasted thereby burning off sulfur, arsenic and stibnite and converting the sulfides to oxides.

5. The calcine produced (135 tpd.) contains 5 oz. of gold per ton and 1.25% arsenic is then quenched and washed and filtered twice. The first filtrate (50 #pd. arsenic) is passed on to tailings and the second filtrate is reused in sand preparation (making the sand fluid so that it may be pumped into abandoned shafts). The liquid seeps out of the sand and enters the mine water which is pumped to Baker Creek.

6. In a cyanidation process the filter cake is ground in a cyanide solution (RaCN + CaO) and the gold is leached into solution by the cyanide and separated by settling.

7. The solution passes on to a precipitation process in which the gold concentrate is precipitated by the further addition of zinc and sodium cyanide. Part of the barren solution is reused in the solution feed to the secondary cyanidation process and the rest, containing 25 #pd. of arsenic, passes on to tailings.

8. The residue is combined with low yield floatation tailings and passed to a secondary cyanidation unit. The solution from this flows to the precipitation unit and the residue, containing 20 #pd. of arsenic, is tailings.

9. The gases from the roasting process (step 4 above) are passed through two hot (700°F.) Cottrell units, operating in parallel in which the gold-bearing dust is precipitated.

10. The hot gases are cooled with air to 230°F. and passed to the Dracco baghouse. Precipitated arsenic trioxide dust (30,059.9 #pd. of arsenic) is separated by the orlon bags and pumped to underground storage, and the gases containing 260 #pd. of arsenic pass on up the stack.

11. The gold-bearing dust from the hot Cottrell unit, apparently originating in the finest particles of the grinding process is then pumped (screw conveyor) to the dust treatment plant. In general there is employed a cyanide leaching with in-pulp addition of activated carbon in a batch process.

The dust is quenched with water, 273 tpd., and passed through a 28 mesh screen, (the screenings rejected) and thickened; the overflow water containing 50 #pd. of arsenic passes out to tailings.

The gold is leached with cyanide at pH 7.8, and then adsorbed with activated carbon. The activated carbon is then separated with a 35 mesh vibrating screen and washed in a hydraulic cone. The wash water flows to the tailings. The carbon, containing 3.3 #pd. of arsenic, is dried and shipped to a smelter.

In the years since 1961, during the period from May 16 to September 30, stored calcine (80 tpd.) has been given thermal treatment. It is repulped with water, pumped to the mill, thickened by settling and filtering, and then treated in an 80 ft. kiln. The solids from this thermal treatment process join the main calcine circuit late in the process (No. 8 agitator) and then flow to the secondary cyanide circuit.

The gases contain arsenic, 123 #pd., but this is entirely redissolved in scrubbing on account of the acidity of the water, the pH being lowered to 2.0 by the sulfur (3200 #pd.) which is also dissolved by the scrub water.

Ponding Treatment of Tailings

The tailings from Giant Mines are discharged into Bow Lake, which is now dammed at several places and is much larger than the original lake. During that portion of year from October 1 to May 15, the dissolved arsenic in the tailings is 192.4 #pd., and that in the effluent from Bow Lake is 83.0 #pd. In the period May 16 to September 30, the corresponding figures are 316 #pd.* and 156 #pd.**. The difference is presumed to be precipitated by natural settlement and by flocculation with ferric iron which coagulates in the pond. The ferric iron is present in large quantities in the tailings. It is apparent that this sedimentation process continues after the effluent from Bow Lake reaches the bay.

* Approximately
** Assuming same proportion of sedimentation

TABLE C-1

CONCENTRATION OF ARSENIC IN WATER SUPPLIES

YELLOWKNIFE, N.W.T.

(mg/l)

Date	Giant Mines Supply	Public Supply	Con Mine Supply	Mouth Baker Creek	Bridge Latham Island	Flow* Rate cfs.	Average** Dilution (mg/l)
1961***							
Jan. 23		.10	.01			777	.02
27		.02	.02			729	.02
Feb. 12		.02	.02			729	.02
Mar. 12		.02	.02			636	.02
Apr. 12		.02	.02			600	.03
26	<.01						
27	<.01						
May 2	.02						
8	.02						
12		.04	.04			604	.03
15	.01						
16	.01						
19	.01						
20	.01						
22	.03						
23	.02						
24	.02						
25	.01						
26	.01						
31 AM	.07						
31 PM	<.01						

* Daily flow rate as supplied by Water Resources Division plus 12% increment, which is approximately the flow from Cameron River. Flow rates after September 1962 aren't yet available.

** Assuming 83#/day arsenic throughout the year and an additional 61#/day during the period from May 15 to September 30 in the years 1961 to 1963 and neglecting that resulting from runoff. See Appendix C.

Assuming complete mixing of the arsenic in the water of the bay, which is never the case. In winter the water is protected from the winds by the ice cover, so that there are no wind-caused currents and therefore much less mixing.

***In November 1958 Giant Mines began using a bay filter unit, which removes approximately 99% of the arsenic from the stack wastes. In the summer of 1961 Giant Mines began reprocessing stored calcine. For these reasons records prior to 1961 aren't included.

Date	Giant Mines Supply	Public Supply	Con Mine Supply	Mouth Baker Creek	Bridge Latham Island	Flow Rate cfs.	Average Dilution (mg/l)
1961							
June 6	.02						
9	.32						
14	.33	.04	.04			939	.03
15	.47						
16	.11						
17	.11						
21	.18						
23	.20						
24	.15						
27	.08						
July 12		.03	.02			780	.03
14	.09						
Aug. 12		.02	.02			1251	.03
22	.01						
23	.01						
25	.01						
Sept. 12		.02	.03			930	.03
Oct. 2	.21						
3	.07						
4	.07						
5	.11						
6	.04						
7	.08						
10	.20						
11	.14						
12	.22						
14	.15						
19	.16						
20	.08						
23	.05						
24	.09						
25	.05						
26	.03						
30	.05						
31	.08						
Nov. 1	.03						
2	.13						
4	.07						
6	.08						
7	.08						
8	.05*						
8	< .01*						
9	.05						
13	.06						
14	.06						
15	.05						
16	.04						
17	.05						
20	.08						
21	.07						
22	.08						
24	.07						
25	.16						
27	.08						
28	.09						
29	.23						

* Different times of day.

Date		Giant Mines Supply	Public Supply	Con Mine Supply	Mouth Baker Creek	Bridge Latham Island	Flow Rate cfs.	Average Dilution (mg/l)
1961								
Dec.	4	.05						
	5	.03						
	7	.04						
	8	.03						
	11	.04						
	12	.04						
	13	.03						
	14	.04						
	15	.02						
	16	.06						
	18	.06						
	21	<.01						
	27	.01						
	28	<.01						
	29	.02						
	30	.04						
1962								
Jan.	2	.01						
	3	.03						
	5	.04						
	9	.04						
	11	.03						
	12	.03						
	13	.03						
	14	.03						
	15	.04	<.01	<.01			569	.03
	22	.03						
Mar.	3		.01	.02			545	.03
	12		.03	.03			540	.03
	28	.03						
	29	.08						
	30	.04						
	31	.03						
Apr.	2	.09						
	3	.02						
	4	.01						
	5	.01						
	9	.08						
	10	.02						
	12	.05	.04	.02			553	.03
	16	.02						
	17	.04						
	18	.08						
	19	.02						
	21	.05						
	23	.05						
	24	.04						
	25	.06						
	27	.04						
	28	.11						
	30	.07						
May								
	1	<.01	.01	.02			558	.03
	3	.07						
	4	.04						
	5	.03						
	7	.15						
	8	.05						
	9	.05						
	10	.04						

Date	Giant Mines Supply	Public Supply	Con Mine Supply	Mouth Baker Creek	Bridge Latham Island	Flow Rate cfs.	Average Dilution (mg/l)
1962							
May 11	.04						
12	.03	.04	.04			481	.03
14	.03						
15	.06						
16	.05						
17	.14						
18	.10						
19	.09						
22	.07						
23	.05						
24	.04						
25	.03						
26	.06						
29	.02						
30	.03						
31	.02						
June 1	.03						
2	.01						
4	.06						
6	1.15						
8	.31						
9	.17						
12	.15	.09	.06			621	.04
13	.11						
14	.15						
15	.14						
16	.18						
18	.23						
19	.33						
20	.10						
21	.11						
22	.07						
July 3	.33						
7	.30						
9	.45						
10	.05						
12	.10	.06	.06			702	.04
13	.08						
14	.16						
16	.52						
19	.57						
20	.04	.05	.04			662	.04
23	.65						
24	.20						
27	.45						
28	.30						
Aug. 2	.15						
3	.09						
8	.09						
12		.12	.12			857	.03
14	.28						
17	.07						
18	.08						
22	.20						
24	.04						
25	.08						
31	.07						

Date		Giant Mines Supply	Public Supply	Con Mine Supply	Mouth Baker Creek	Bridge Latham Island	Flow Rate cfs.	Average Dilution (mg/l)
1962								
Sept.	1	.08						
	3	.11						
	11	.09						
	12	.06	.12	.07			1181	.02
	13	.09						
	17	.09						
	19	.13						
	30	.09						
Oct.	1	.09						
	2	.09						
	12	.05	.12	.07				
	18	.09						
	20	.13	.04	.02				
	25	.12						
Nov.	1	.13						
	6	.13						
	12	.09	.07	.08				
Dec.	12		.06	.07				
	17	<.01	.03	.03				
	22	.03						
	30	.02	.04	.03				
1963								
Jan.	2	<.01	.02	.02				
	3	.01						
	7	.01						
	12		.04	.03				
Feb.	12		.03	.04				
Mar.	3	.01						
	12		.04	.04				
	24	<.01	.02	.02				
Apr.	12		.04	.04				
May	8	.02	.03	.02	3.8	0.2		
	12		.11	.06				
June	8	.49						
	12		.05	.05				
	15	.50						
	18	.13						
	19	.28						
	20	.23						
	21	.20						
	24	.14						
	25	.15						
	26	.28						
	28	.11						

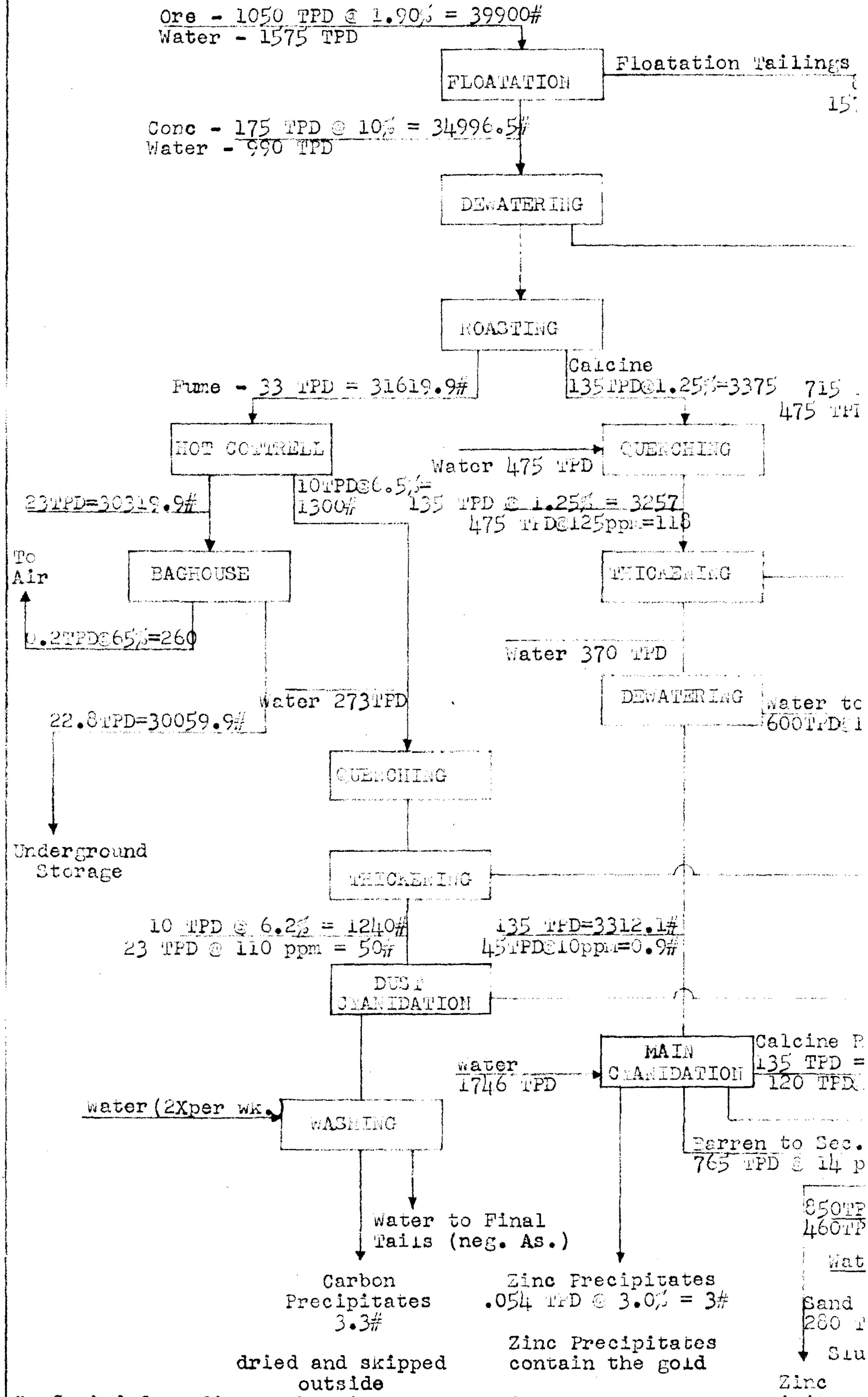
Date		Giant Mines Supply	Public Supply	Con Mine Supply	Mouth Baker Creek	Bridge Latham Island	Flow Rate cfs.	Average Dilution (mg/l)
1963								
August	12		.04	.04				
Sept.	4	.46	.01	.01				
	12		.04	.03				
	20	.08						
Oct.	11	<.01	<.01	<.01				
	17	.01	.02	.01				
Nov.	19	.01	.02	.01	10.5			
Dec.	4	<.01	.02	.03				

FIGURE C-1

N.B. Figure C
May 16 t

MILL FLOW DIAGRAM*

WITH ARSENIC BALANCE



* Copied from diagram by Giant Mines Ltd.
All figures reproduced as supplied.

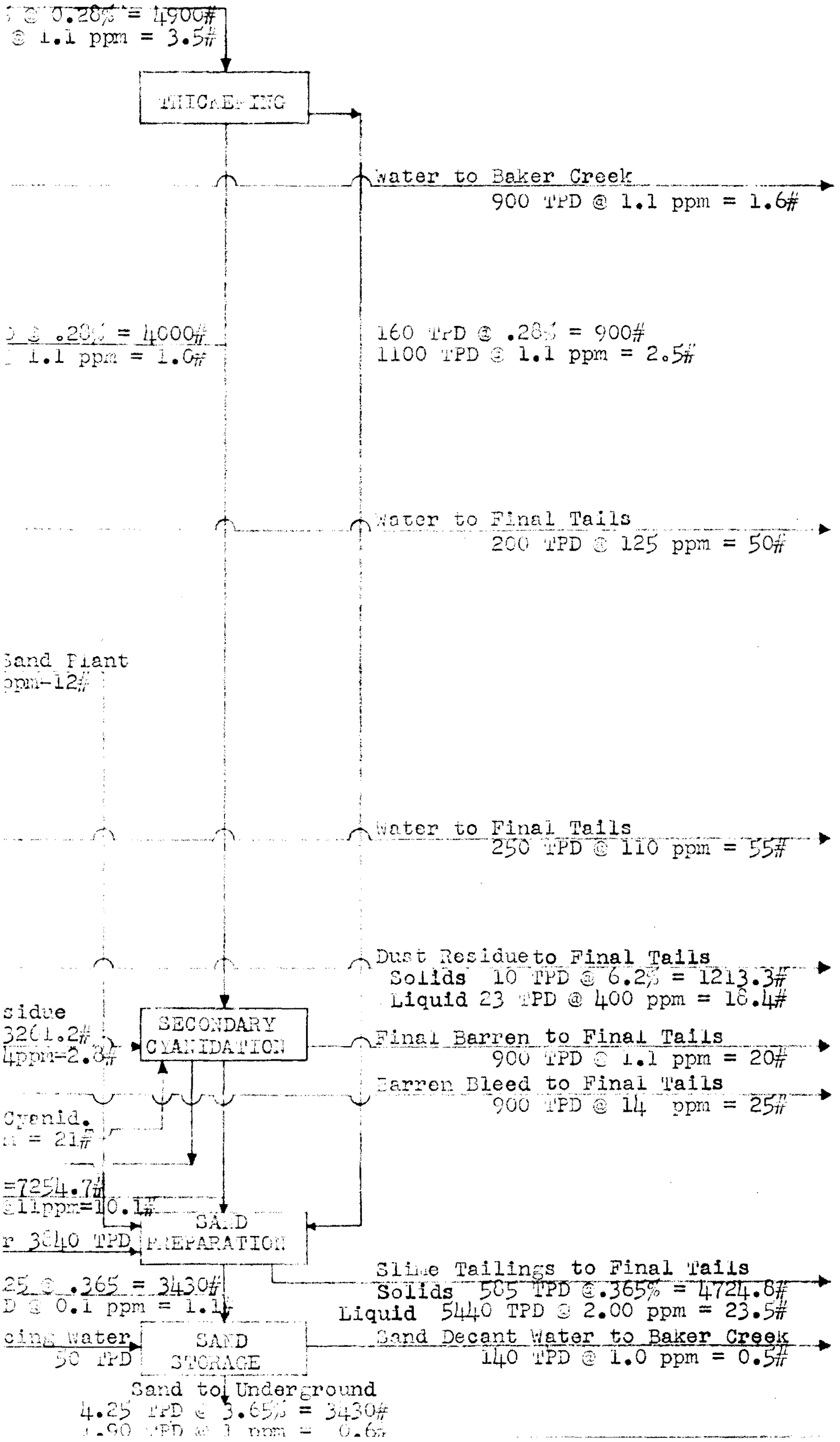
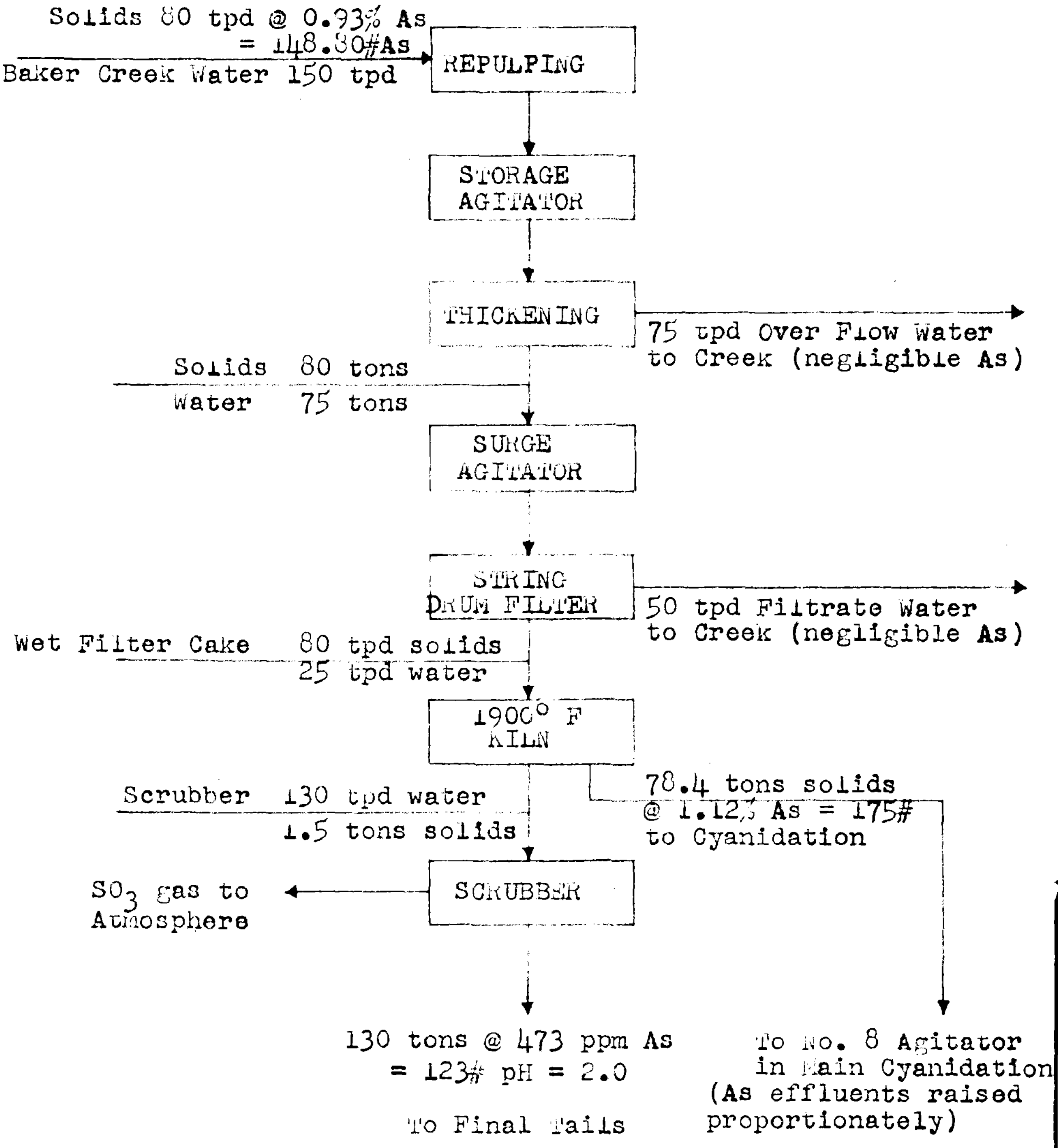

@ 0.28% = 4900#
@ 1.1 ppm = 3.5#
THICKENING
Water to Baker Creek
900 TPD @ 1.1 ppm = 1.6#
@ .28% = 4000#
1.1 ppm = 1.6#
160 TPD @ .28% = 900#
1100 TPD @ 1.1 ppm = 2.5#
Water to Final Tails
200 TPD @ 125 ppm = 50#
Sand Plant
ppm-12#
Water to Final Tails
250 TPD @ 110 ppm = 55#
Dust Residue to Final Tails
Solids 10 TPD @ 6.2% = 1213.3#
Liquid 23 TPD @ 400 ppm = 18.4#
sidue
3261.2#
4ppm=2.8#
SECONDARY CYANIDATION
Final Barren to Final Tails
900 TPD @ 1.1 ppm = 20#
Barren Bleed to Final Tails
900 TPD @ 14 ppm = 25#
Cyanid.
= 21#
=7254.7#
lppm=10.1#
r 3840 TPD
SAND PREPARATION
Slime Tailings to Final Tails
Solids 505 TPD @.365% = 4724.8#
Liquid 5440 TPD @ 2.00 ppm = 23.5#
25 @ .365 = 3430#
D @ 0.1 ppm = 1.1#
cing Water
50 TPD
SAND STORAGE
Sand Decant Water to Baker Creek
140 TPD @ 1.0 ppm = 0.5#
Sand to Underground
4.25 TPD @ 3.65% = 3430#
.90 TPD @ 1 ppm = 0.6#

FIGURE 5-2

MILL FLOW DIAGRAM WITH ARSENIC BALANCE

CALCINE RESIDUE STORAGE*



* Seasonal Operation, May 16 to Sept. 30.

APPENDIX D

SUMMARY OF YELLOWKNIFE RIVER FLOW DATA

The water flowing into Yellowknife Bay at the mouth of Yellowknife River comes from two sources, the main branch and Cameron River. The flow from the main branch is controlled somewhat at the power dam, however there was a heavy overflow at the time of the study. The flow is measured daily at this site, and from there it flows into the north end of Prosperous Lake.

Cameron River flows into Prosperous Lake, near the north end. The discharge from this river is estimated to be one-ninth of the total flow, based on data on the flow of water in this river gathered during the summer of 1939.

The daily flow fluctuations as controlled somewhat by the dam, are presumed to be evened out in Prosperous Lake, which is approximately 12 sq. miles in area and 6 miles from inlet to outlet, and in the 6 miles of ¼ mile wide river below the outlet.

COMPARISON OF DISCHARGES--1939

YELLOWKNIFE AND CAMERON RIVERS

Monthly Mean Discharges in cfs.

	March	April	May	June	July
Yellowknife River at Inlet to Prosperous Lake	446	392	450	508	480
Cameron River near Mouth.	61.0	42.9	65.0	64.0	59.0
Ratio	0.137	0.110	0.145	0.126	0.123
Average Ratio	0.126 or 1:8				

TOTAL FLOW OF YELLOWKNIFE RIVER (cfs.)

During Study Period

Date	Main Branch	Two-day Average	Cameron R. (Presume ratio 1:8)	Total Flow
July.				
14	3,177			
15	3,243	3,210	402	3,612
16	3,379	3,311	414	3,725
17	3,386	3,383	422	3,805

July mean 2,886

MEAN MONTHLY DISCHARGES

YELLOWKNIFE RIVER INTO PROSPEROUS LAKE

(cu. ft. per sec.)

Annual Period Ending September

	1952	1953	1954	1955	1956	1957	1958	1959	1960	1961	1962
Oct.	901	1370	836	871	920	862	1544	1488	2199	999	635
Nov.	790	1151	990	792	777	895	1198	1311	1967	844	519
Dec.	662	1009	1125	768	675	843	999	1173	1678	751	485
Jan.	561	874	1005	740	602	772	879	977	1403	691	507
Feb.	640	783	852	678	544	695	746	875	1130	611	501
Mar.	559	647	745	630	530	611	646	718	910	579	485
Apr.	557	533	608	603	507	569	566	631	759	545	496
May	1380	592	821	710	505	645	1252	857	1267	656	466
June	2340	641	1116	1129	577	930	1746	1663	2194	831	586
July	2380	549	1036	2135	506	2302	2050	2498	2879	782	617
Aug.	1830	562	1272	1592	740	2806	1702	2775	1975	1061	942
Sept.	1620	772	1009	1184	862	2115	1634	2432	1341	813	1034
Mean	1177	790	952	989	646	1175	1251	1454	1646	765	606
Maximum Daily Flow	2816 June 20	1496 Oct. 3	1366 Dec. 30	2453 July 6	1043 Sept. 25	3212 July 31	2152 July 12	3219 July 29	3322 July 5	1140 Aug. 9	1280 Aug. 26
Minimum Daily Flow	518 Apr. 2	159 Apr. 9	540 May 3	490 May 7	263 Aug. 5	501 May 6	437 May 3	554 May 12	729 Apr. 21	527 Apr. 15 & May 18	300 July 17

All data supplied by Water Resources Division, Dept. of Northern Affairs & National Resources.

APPENDIX E

SUMMARY OF WIND DATA DURING STUDY*

Wind speeds in miles per hour.

Hours after Midnight	July 15 Direction	July 15 Velocity	July 16 Direction	July 16 Velocity	July 17 Direction	July 17 Velocity	July 18 Direction	July 18 Velocity
1			S	9	S	4	W	5
2			SSW	12	SW	5	SE	7
3			SSW	14	WSW	5	SE	8
4			SSW	10	SW	5	SE	6
5			S	6	W	7	SE	9
6			SW	6	W	4	SE	5
7			SW	9	WNW	5	SSE	10
8			SW	4	W	6	SE	10
9			N	4	NW	9	SE	13
10			E	11	N	3	SSE	13
11			Calm	-	N	2	S	14
12			Calm	-	NE	8	SSE	17
13	NW	13	Calm	-	N	7	S	13
14	WNW	10	NNW	3	E	3	S	15
15	NW	10	N	11	N	6	SSW	14
16	NW	13	N	13	Calm	-	SSW	15
17	NW	12	NNE	10	SE	7	S	14
18	WNW	12	N	15	S	6	SSE	10
19	WSW	9	NE	10	S	8	SSE	10
20	SW	10	NE	10	SSW	8	S	5
21	SSW	9	ENE	4	S	8	S	10
22	SSW	9	Calm	-	SSW	10	S	8
23	SSW	10	SSE	3	SW	10	NW	6
24	S	7	S	3	W	12		

---

* All data supplied by Meteorological Service of Canada.

PERCENTAGE WIND DIRECTION AND AVERAGE WIND SPEED

YELLOWKNIFE, N.W.T.

1951 to 1954 Inclusive

	May		June		July		August		September		October	
Direction	% of Time	Speed (mph)	% of Time	Speed (mph)	% of Time	Speed (mph)	% of Time	Speed (mph)	% of Time	Speed (mph)	% of Time	Speed (mph)
N	11	10.2	14	11.3	20	12.0	12	10.2	22	11.0	13	11.2
NE	16	10.0	21	11.6	13	10.4	11	8.9	15	8.5	13	10.3
E	23	10.5	13	8.1	9	8.0	17	8.7	20	9.7	25	11.3
SE	21	11.7	15	10.4	14	10.0	20	10.7	17	12.5	11	13.8
S	18	10.2	20	10.4	15	9.6	17	10.8	8	9.2	8	13.9
SW	5	8.4	8	8.7	7	10.1	5	7.4	2	7.9	6	10.2
W	3	9.7	3	8.4	7	10.0	7	10.3	6	9.9	11	10.2
NW	5	10.3	6	12.0	15	11.8	11	12.5	8	13.0	13	13.5
Calm	less than ½		less than ½		less than ½		less than ½		less than ½		less than ½	
all directions		10.5		10.4		10.5		10.2		10.4		11.7

APPENDIX F

DISCUSSION OF ERRORS

Because of the shortage of personnel available for this study, many short cuts were taken. Many of the conclusions are therefore coarse, however they are satisfactory for providing meaningful direction to the planning of arsenic wastes disposal and controls.

The errors have been discussed in other parts of the report. In summary, the more important ones are as follows:

1. The dye tracers provide an indication of the location and direction of many, but not all, of the water currents in the bay. However, there is only a rough estimation of the extent of the variable mixing which will be obtained when arsenic wastes are discharged to the Narrows.

2. The amount of arsenic wastes contained in the runoff water, in spring melt and rains, has been practically ignored in the report. The arsenic level in the water in Yellowknife is affected by this source, especially during the spring runoff in May and June. The reason why this part of the study wasn't made is that it would have been too time-consuming in view of (a) this being a small fraction of the total arsenic wastes problem, and (b) the information obtained would have little practical value.

Fall pans have been placed throughout the affected runoff area and data have been collected since 1951. In general, arsenic has been settling in the drainage area at rates up to 2 lb. per acre per year. However, it would require (a) a long study of the hydrological factors and (b) an evaluation of the amount of arsenic which has been washed into the soil and (c) the extent and rate at which this will eventually wash through to the water courses.

3. The stated amount of arsenic discharged to the tailings pond is based on a survey made during the winter of 1962-3. However, this is subject to wide variation as different ores are mined and as the processes are changed.

The amount of precipitation in the tailings pond also varies (a) as the physical features of the pond change due to adding dams and filling by sedimentation, and (b) as the amount of ferric iron in the tailings varies.

4. Because of the variability of the water currents and consequent variable mixing, the arsenic tests on water samples provide only a rough indication of the arsenic content.

5. The physiological effects resulting from arsenic in drinking water, in the low levels as exist at Yellowknife, can't be evaluated accurately, because there is too little factual information available.

APPENDIX G

CHOICE OF TRACERS

Prior to making the survey consideration was given to several methods of studying the currents. In all but one case tracers of one type or another would be introduced at the existing or proposed sewage or mill tailings outfall points.

Four different types of traces and six different experimental methods were considered.

1. Feeding chemicals continuously which would dissolve in the water and their movement determined from samples for quantitative chemical analyses, taken across cross-sections in the bay over a long period of time.

2. Feeding chemicals as above, and taking samples over a long period of time at the existing water intakes.

3. & 4. Feeding a radioactive tracer with a long half-life specifically tritium, and making observations as in (1) and (2).

5. Observing the movement of floats.

6. Observing the movement of any one of several colored dyes which dissolve in water.

7. Anchoring a boat successively at different places in the bay and making velocity and direction measurements at various depths.

The principle of using chemicals for tracers was discarded for several reasons:

1. The immense task of taking samples, making the quantitative tests, compiling and analysing the results, was beyond the work capacity of one man, which was all the staff available for this job.

2. The cost of suitable chemicals in sufficient quantities is very high considering the high transportation charges to Yellowknife.

3. The introduction of a ton or so of chemicals would require hiring several men and a very large boat which wasn't readily available. This method of study was used in San Francisco Bay.

4. There were indications of circulating currents in the bay, and testing for concentration of a chemical wouldn't differentiate between the chemical which was moving across the sampling point the first time and that which had moved more than once over the sampling point.

We didn't take bottles of water for dilution estimation because the dye was too dilute for this purpose approximately a half mile from the discharge point.

Dye	Rhodamine BN 450	Rhodamine CGDN 500	Eosine Y 130	Sodium Fluorescene
Price*				
100#	$2.91	$5.78	$2.51	-
25#	2.94	5.81	2.54	-
5#	3.16	6.03	2.57	$7.20
Color in strong solution	deep red	bright red	orange	yellow
Color in weak solution	bright red	bright red	orange	green
dilution visible in nessler tubes	0.1 mg/l. but not 0.01 mg/l.	same	same	same

The weight of the dye-water mixture wasn't checked in a laboratory, but it did appear that the mixture was sufficiently light that density currents weren't created.

LESSONS LEARNED RE HANDLING OF DYES

1. The dyes as sold are very fine light powders which are messy to handle. It takes three or more days for the dye to wash and wear off the hands and face, and is a permanent dye on clothes and suede shoes. It seems to be impossible to prevent its getting all over the floor and equipment whenever it is handled. When discharging from a motor boat, wind eddies blow it into the boat and all over the outboard motor and stern of boat from which it is difficult to remove.

Small lumps of dye powder settle through the water to the bottom, and in this way there is a small waste. However, this was reduced to a minimum by discharging the dye into the churning water in front of the propeller of the outboard motor. The waste was probably less than 5%.

Experiments in the laboratory showed that the discharge operation took much too long when the dye was tied inside a cloth bag and sloshed around in the water.

The operation would have been much more satisfactory if the dye had been purchased in prepackaged paper bags (approx. 10 lb.) and fed below water in front of the propellers using a hopper arrangement with a lid. The bag of dye could have been placed in a metal container clamped to the boat stern.

* Prices supplied by Canadian Industries Ltd., Montreal, P.Q.

The principle of using a radioactive tracer was discarded for two reasons:

1. The expense of the study would have been excessive, principally due to the high cost of testing hundreds of samples, approximately $5 each.

2. As would be the case with chemical tracers, there would be no way of distinguishing that which was moving across the sampling point initially and that which was moving across for a second or a third time.

The principle of using floats was considered seriously, but discarded because compiling and studying the data would have required a long study. Considering the time involved and the shortage of staff, this would have been an impossible study.

The principle of making direct readings with a current meter was discarded because a large number of trained technicians, who were not available, would have been required to make the readings.

The principle of dissolving a dye in the water was chosen for several reasons:

1. The total time required to drop the dye at several places and to make observations from the air was less than would be the case with the other methods considered.

2. The cost of the dyes was much less than the cost of chemicals because it could be observed in dilutions of approximately 1:100,000,000 whereas with most salts the results would be questionable in concentration of less than 1:100,000 i.e. 1,000 times the concentration.

3. The dye could easily be discharged from a small motor boat.

4. There would be a clear indication of the movement of the water containing the dye, and no question as to whether it had moved once or more over the sampling point. The method was tested in a prior experiment by discharging 5 lb. of the dye in a lake in northern Alberta and watching its movement. It was found to be a suitable tracer.

CHOICE OF DYE

Four different dyes were considered as shown in the table below. Rhodamine BN 450 was chosen because (1) it is the least expensive and (2) it is the most vivid when observed in water with the naked eye. It is observable in the water body in dilutions of approximately 0.005 mg/l. It showed upon color slides (Kodachrome II) in dilutions approximately 0.01 mg/l, although in these high dilutions the prints, which were made from these slides, weren't very clear. The color didn't show up in black and white photos even in low dilutions, as determined in the northern Alberta study.

APPENDIX H

PHYSIOLOGICAL EFFECTS OF ARSENIC IN DRINKING WATER

Internal assimilation of arsenic may cause acute toxic, chronic toxic and carcinogenic* (cancer-causing) effects. The last-named effect is the only one of concern at Yellowknife, where the concentration of arsenic is generally less than 0.05 mg/l.

Arsenic plays no part in natural biological processes; however arsenical compounds have been administered as a tonic. Arsenic-containing water from several wells in Europe have been sold for therapeutic purposes. The location of these wells and the arsenic content of the water are as follows:

Guberquelle, Boxnie	6 mg/l
Levico, Northern Italy	6 mg/l
Duerkheim, Palatinate	17.4 mg/l
Roncegno, Northern Italy	42.6 mg/l

Formerly, arsenical compounds were used internally for therapeutic purposes. Potassium arsenite solution, generally known as Fowler's solution (0.76% As) was used in the treatment of blood dyscrasias, myelogenous leukemia, chronic eczema, skin disorders such as psoriasis and syphilis.[1,3] Arsenic trioxide tablets (76% As) have been used in the treatment of chronic bronchitis, asthma and pernicous anemia. Donovan's solution (1% AsI_3 or 0.28% As) was also used occasionally.

Many organic arsenical compounds were used. Carbarsone, (p-Ureidobenzenearsonic acid,) tablets (28% As) were used for the treatment of intestinal amebiasis, amebic dysentery and pemphigus,[1] salvarson (diamino-dihydroxy arsenobenzene) for syphilis, and Atoxyl (sodium-aminophenyl arsenate)for protozoal infections.[2] Arsenical compounds are still used in the treatment of amebiasis.

External Exposure to Arsenical Compounds

Arsenic may be absorbed through the skin and act as an irritant. Among workers in mines, smelting works, sheep dip factories and farmers using arsenical insecticides, there have been hundreds of cases of skin cancer which have been attributed to external exposure to dust-containing arsenic compounds;* however it is very rare considering the total number of people who have been similarly exposed. The exposure period varied from 4 to 46 years, with an average of about 25 years time elapse between the beginning of the exposure and the onset of symptoms.[6]

On the other hand, there are no known cases in which the short-term external application of arsenical ointments have produced skin cancer.

Toxicity to Fish and Fish Food Organisms

In the small concentrations of arsenic, such as exisit in the water of Yellowknife Bay (maximum 0.46 mg/l) it is not believed to be a factor deliterious to the life of fish or fish food organisms. There is

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* Indicated by statistical methods of analyses.

experimental evidence that sodium arsenite is toxic to Daphnia magna (water flee) in concentrations of 1 mg/l As, to chironomid larvae (larvae of a small fly) mayfly nymphs (insect) and amphipods (freshwater shrimps) in concentrations of 2 to 3 mg/l As, and to minnows (Phoxinus L.) in 953 mg/l As in 55 days.[3]

The arsenic content is not of importance in the health of gold fish and tropical fish. If in a particular case the water was never changed, the arsenic in the added water, replacing that which evaporates, would result in a toxic concentration being attained eventually. However, this is a very remote possibility and not worthy of consideration.

Acute Toxicity to Humans

Inorganic trivalent arsenical compounds are strong protoplasmic poisons capable of causing death within 24 hours when ingested in large amounts. The lethal dose to healthy adults is approximately 100 mg As_2O_3 in solution. There have been many cases where much greater doses in the forms of white powder (presumably As_2O_3 or As_2O_5), yellow powder (As_2S_2 or Paris green ($3\ cu\ (AsO_2)_2 \cdot Cu\ (C_2H_3O_2)_2$) haven't been fatal probably because some of the powder may not have dissolved and thus available for absorption in the intestine. The pentavalent form is less toxic, but in small quantities it is readily reduced in the body to the trivalent state.[4]

The toxicity of the arsenous ion (As^{+++}) is largely due to interference with enzymatic activity in the cells of those tissues in which it concentrates, mainly the liver, kidney, and intestinal walls. This may be due to its reaction with SH groups and thereby interfering with cellular respiration.[4,5]

Organic arsenical compounds, such as many therapeutic medicines, are less toxic because the arsenic ion isn't readily available as a cellular toxicant. In rare cases the arsenic exerts violent toxic effects which may be either (1) allergic in nature or (2) chronic toxicity resulting from the liberation of inorganic arsenic compounds from the parent substance, and subsequently accumulating in the body.[5]

Chronic Toxicity

After a single dose of arsenic has been swallowed it quickly accumulates in various organs and begins to be excreted via the urine and faeces and to a minor extent from the sweat, tears and hair. In two or three weeks time it will be eliminated from all of the organs, but some remains in the bones and skin, and requires several months for final elimination. As a result of this slow elimination of arsenic, successive doses result in accumulation of this metal in parenchymal organs, particularly the liver and kidney, and toxic effects are produced by direct poisoning of the tissues involved, and damage to the capillary bed.

Arsenic Gas Poisoning

The physiological effect of arsenic gas (AsH_3) is in a different category, and is discussed only for the sake of completeness. It causes massive lysis (dissolution) of red blood cells, and tissue damage by arsenite which is formed.

Arsenical Cancer

Arsenical cancer is a complication of chronic arsenic poisoning and its occurence is very rare. This effect can be attributed to arsenic after statistical analysis of the data.[7,8] It appears that the likelihood of this occurence increases with the greater number of arsenous ions and with the prolonged period of cellular exposure.

The skin is by far the most frequent part of the body affected, and the next most frequently affected parts are in order (1) mouth and esophagus, (2) respiratory tract, and (3) renal (urinary) tract.

Cancer may be caused by arsenic which has been taken as in drinking water, food or medicine, or breathed into lungs and bronchial tubes as a dust component in the air, or absorbed through the skin upon contact with arsenical dusts or solutions. Examples are bountiful dating back as far as 1825. Most cases occurred among workers in smelters and factories who breathed arsenical fumes or dust-laden air, or whose skins were often in contact with arsenical dusts or solutions. Many cases occurred among patients taking arsenical drugs internally for the treatment of a variety of ailments and among people drinking arsenic-contaminated water.

Tolerance to Arsenic

It is a general belief that people can acquire an immunity to the toxic effects of arsenic. This partial misconception is based largely on the facts that the "arsenic eaters of Styria, S.E. Austria", many of whom regularly took almost half a gram of arsenous oxide. Apparently they didn't suffer from the irritating effects associated with acute poisoning however they developed tumors frequently, and in one study it was found that 13% of the deaths in Styria were of this cause.[7] It is not a true tolerance because the arsenic was taken while fasting and no water is drunk for some hours afterwards,[2] and for these reasons the arsenic may not have become dissolved while in the intestines.

History of Chronic Toxicity at Yellowknife

Although chronic toxicity has been a factor at Yellowknife in the past, this isn't the case at present. In the spring of 1949 a herd of fifteen cattle died and several chickens were sick apparently as a result of drinking water containing arsenic trioxide in the concentration of 1.2 mg/l As. The water was runoff from the snow in the surrounding area which had been contaminated by arsenical dust settling out of the air.

In April, 1951, an Indian child died and several other Indians were sick as a result of drinking water obtained from snow water, although there may have been contributory causes such as malnutrition. They lived on the north tip of Latham Island two miles southeast of the smokestack of Giant Mines and three miles northeast of that of Con Mine.

Danger Level of Arsenic Assimilation

Acute Toxicity

The minimum fatal dose (acute) has been estimated to be 0.8 to 2.4 mg/kgm. of body weight.[4] Assuming worst conditions, that of a 10 lb. baby being fed a formula made from powdered milk and water (2 lb. of water), conditions from this minimum fatal dose would be obtained in one day if the water contained 4 to 12 mg/l. of arsenic.

The arsenic eaters of Styria, Austria consumed ½ gm. of arsenic oxide once or twice a week, which is equivalent to drinking 4 lb. of water (8 std. cups) per day containing 60 to 120 mg/l As. However, the arsenic was taken in powder form, some of it may have passed through the body without dissolving, so this isn't a true guide.

Chronic Toxicity

The minimum fatal dose (chronic) hasn't been estimated. No one made an estimate of the arsenic content of the drinking water (melted from arsenic-contaminated snow) of the baby who died in Yellowknife in 1951.

For over a hundred years people at Richenstein, Silesia, Poland (formerly East Germany), drank water from a brook containing 12 mg/l of arsenic. Many had "Richenstein's disease", with symptoms referable to the gastrointestinal tract, ulcers in the mouth, perforation of the nasal septum, parathesias, and especially melanosis (brown-colored skin) and kerotic warts on fingers and hands.

In Argentina, 6 % of the wells produce water containing between 0.1 and 0.3 mg/l of As. Many people in a wide area in the southeast part of the Province of Cordoba drink well water containing up to 4.5 mg/l of As. After living five to six years there, many people develop Ayerza's* disease (severe keratosis of the hands and feet) liver and kidney ailments which are often fatal. It has been stated that chronic arsenosis may result after prolonged use of water containing 0.3 mg/l of arsenic. It is reported to be more toxic when there are other dissolved heavy metals, particularly vanadium in the water.

* First noted by Ayerza at Belle-Ville.

Mackenzie cites the case of water, which contained 1/80 grain per imp. gal. (0.18 mg/l), causing several cases of arsenical poisoning. The water had been collected from two roofs which had been painted with "pyrites"[10]. It is reasonable to assume that the concentration of arsenic in the water had been higher, previous to the sickness and resulting investigation.

The drinking water for a large part of Los Angeles contained over 1.0 mg/l for several months.[11] No incidents of arsenic poisoning were reported, but medical practicionary may not have noticed unexpected symptoms of arsenic poisoning.

The water in a 94 ft. deep well on a farm near Mador, Ontario produced water with an arsenic content of 10 mg/l. Within a year or so of moving there, people noticed their general malaise and nausea and after two or three years the hyperkeratosis of the hands. The father died of chronic nephritis (1932) after living there five years and three of the four children born there died a few days after birth (1928, 1929 and 1932) for no apparent cause. All babies had dark skins, but were otherwise of healthy appearance.[12]

There have been many experiments on rats and other animals, but the results aren't directly applicable because arsenic is more toxic to man, apparently due to the higher development of his nervous system.[4] Cows at Yellowknife died (with diarrhoea, which is a typical symptom of arsenic poisoning) after drinking water containing arsenic trioxide in the concentration 1.2 mg/l As over a period of several weeks. Here again these results aren't directly applicable because (1) milk cows drink much more water than humans, on a body weight bases, and (2) arsenic is less toxic to animals. Assuming the average cow's (breeds not known) weight at 1300 lb. and water consumption at 100 lb. per day, water consumption is 0.08 lb. of water per lb. wt. A healthy sport-minded schoolboy weighing 130 lb. might consume 4 lb. (8 std. cups) of water, in which case water consumption is 0.03 lb. of water per lb. wt.

Many people have acquired arsenic poisoning and arsenical cancer following the prolonged administration of arsenical drugs internally, principally Fowler's solution (potassium arsenite solution, 1% As_2O_3 or 0.76% As) and by injections. However, there is relatively little factual information regarding the amount of arsenic administered. Table No. 1 contains the information reported by Neubauer[6] in a study of 143 cases of arsenical cancer. Table No. 2 contains information from various papers about arsenic poisoning together with the amount of arsenic administered. Details from many other papers aren't included, because of the lack of information about the amount of arsenic administered.

Arsenical Cancer

There is a wealth of statistical evidence of the carcinogenic nature of arsenic, but there is a paucity of information concerning the amounts of arsenic assimilation and the periods of exposure in these cases.

There is a high incidence of skin-cancer among the people with "Richenstein's disease", in Silesia and "Ayerza's disease", in Argentina.

DETAILS OF CASES OF ARSENICAL CANCER REPORTED BY NEUBAUER[6]

Only 20 of 143 cases are included, the ones with sufficient details of dose rates to compare with arsenic contamination of drinking water.

Case No.	Description	Years from start of treatment to development of arsenical cancer	Duration of Treatment	Dose Fowler's Solution	Drinking Water* Equivalent (mg/l)
20	Carcinoma - Thumb	25	3 mo.	30 drops** daily	6.3
22	Carcinoma - breast	20	20 yr.	15-20 drops daily	3.1 to 4.2
43	multiple epitheliomas	1	1 yr.	2 gm. in 1 yr. (Assume As_2O_3)	2.3
45	multiple epitheliomas	22	9 yr.	As pills*** 3 pills daily	25.1
48	biopsied	-	-	6 drops 3 X daily	3.8
62	Squamous cell Carcinoma - fingers	15	15 yr. (with intervals)	4 to 10 drams (dr) 3 X daily	17.8 to 44.6
65	Squamous cell Carcinoma - near anus	14	6 mo.	30 dr. daily	446
78	multiple cancroids plus 1 basal cell Carcinoma - atypical	27	27 yr.	5 drops 2 X daily (25g in 27 yr.)	0.6 (1.1)
82	Squamous cell Carcinoma - near anus and other parts	22	6 mo.	30 drops daily	6.3
83	Squamous cell carcinoma - upper and lower extremeties, trunk	20	3 wks.	5 drops 3 X daily	3.1
89	Squamous cell, Carcinoma - trunk and leg.	10 to 15	2 yr.	5 drops 3 X daily	3.1

(Cont.)

Case No.	Description	Years from start of treatment to development of arsenical cancer	Duration of Treatment	Dose Fowler's Solution	Drinking Water* Equivalent (mg/l)
92	basal cell Carcinoma - fingers	15	15 yr.	6 drops 3 X daily	3.8
94	Squamous cell Carcinoma - hand	14	10 yr. (with intervals)	15 drops 3 X daily	9.4
98	multiple epitheliomas (basal cell carcinoma)	more than 3	more than 3 yr.	5 to 7 drops 3 X daily	3.1 to 4.4
102	multiple epitheliomas (squamous cell carcinoma)	10	5 yr.	1 to 26 drops 3 X daily total dose 1200 to 1450 ml.	0.6 to 15.7 2.8 to 3.3
105	Bowen's tumor - exilla	30	1 yr.	3 to 16 drops 3 X daily	1.9 to 10.1
109	multiple epitheliomas	27	7 yr.	As pills 15 pills daily each containing 0.1 to 0.4 mg.	0.6 to 2.5
124	multiple epitheliomas (basal cell carcinoma temple)	35	25 yr.	5 to 10 drops 3 X daily	1.0 to 2.1
140	multiple epitheliomas (squamous cell carcinoma chest)	13	-	3 drops 3 X daily total 37,000 drops	1.9
141	multiple epitheliomas (basal cell carcinoma - nipple)	30		total 700 gr. As_2O_3	0.2

* Assume 8 std. cups total daily water consumption

** Assume 20 drops = 1 ml.

*** Assume arsenic trioxide, 2 gm. per pill

DETAILS OF CASES OF ARSENIC POISONING SELECTED FROM MANY PAPERS

Information included is restricted to that containing sufficient details of dose rates to compare with arsenic contamination of drinking water.

No.	Condition Treated	Fowler's Solution Dose Rate	Drinking Water Equivalent (assuming 8 std. cups daily water consumption).	Arsenic Poisoning (other than cancer)
1.	Chronic Eczema, lichen planus and psoriasis.	0.1 ml., 3 X daily, increased by 0.05 ml. daily to reach 0.5 ml. per dose and continued for 1 to 2 weeks.	1.3 mg/l increased gradually over 8 days to 3.2 mg/l and continued 1 to 2 weeks.	chronic frequently
2.	Asthma	1 ml. daily for 15 months.	4.2 mg/l	Chronic frequently. Two cases melanosis one of them showing keratosis and kerotoderma.
3.	Asthma	0.6 ml. daily for 9 months and 0.3 ml. to 0.6 ml. daily for an additional 18 months.	2.5 mg/l for 9 months and 1.3 to 2.5 mg/l for an additional 18 months.	One case. melanosis, keratosis, gastro-enteritis, hepatitis and neuritis.
4.	Asthma	0.25 to 0.5 ml., 3 X daily for 2 years.	3.2 to 6.3 mg/l	dermatitis herpetiformis
5.	Leukemia, psoriasis or dermatitis herpetiformis	0.2 to 0.6 ml., 3 X daily for 2 years or more	2.5 to 7.5 mg/l	Four cases--ciarhosis of the liver with ascites and keratosis.

1. Wise & Wolfe, 1938, J.A.M.A., V. 111, p. 2106
Cannon, 1936, N.Y. State J. Med., V. 36, p. 219
Kandel and LeRoy, 1937, Arch. Int. Med., V. 60, 846

2. J.A.M.A. 1946, V.P. 30, p. 379
Pascher & Wolfe, 1952, J.A.M.A., V. 148, p. 734

3. Silver & Wainman, 1952, V. 150, p. 584

4. Wade & Frazier, 1953, Lancit, V. 1, p. 269

5. Franklin et al, 1950, Am. J. Med. Sc., V. 219, p. 589

Note: Recommended dose rate for protozoal stomach infections is 1 to 5 gm. daily.[2] This is equivalent to drinking water containing 4.2 to 20.9 mg/l As. Dose rate for Donovan's Solution (AsI_3) is 4 to 16 mg. daily.[2] This is equivalent to drinking water containing 0.4 to 1.5 mg/l As.

ARSENICAL CONTAMINATION OF DRINKING WATER WARFARE

For comparison the subject of possible arsenical contamination of drinking water has been considered by Ruchhoft et al. His observations concern a wartime hazard, and these tolerance levels shouldn't be considered as suitable for any emergency during peacetime. Quote.

"The detection and analysis of arsenic in water contaminated with chemical warfare agents" by C.C. Ruchhoft, O.R. Placak and S. Schott, Public Health Reports 58, # 49, 3 Dec. 43, 1761-1771.

"The United States Public Health Service Drinking Water Standards states that arsenic in excess of 0.05 ppm. should not be permitted in water for drinking or culinary purposes. It is suggested, however, that in emergencies where other supplies are not available arsenic in concentrations up to 1 to 2 ppm. might be permitted for several days and concentrations as high as 5.0 ppm. might even be permitted for one day.

"Assuming a water consumption of 2 liters per day (this is 2.12 quarts and is probably high) 4 mg. of arsenic would be ingested daily through use of a water containing 2 ppm. arsenic and 10 mg. would be ingested in one day from the water containing 5 ppm. arsenic. This amount is not excessive. Arsenic trioxide is administered internally in doses of 0.001 to 0.003 gm. three or four times a day. This corresponds to 3 to 9.1 mg. of arsenic per day and is essentially the same as would be obtained by using the contaminated waters previously mentioned.

"The Department of Agriculture's standard of tolerance for arsenic in foodstuffs is 1.4 ppm. and for spray residues is 3.58 ppm.

"McNally states that the commonly accepted figure for a fatal dose of arsenic is 175 to 204 mg.

" The use of contaminated water should not be continued for more than a few days, however, as small quantities of arsenic consumed daily for extended periods of time have been known to produce fatalities". (Page 1763).

STANDARD LIMITS OF ARSENIC IN WATER SUPPLIES

In many countries where there is likely to be arsenic in water supplies, limits of arsenic have been set as a guide to communities in order that they may decide what water is suitable for consumption. The first standards were established in England in 1903.[4] A Royal Commission headed by Lord Kelvin investigated 6,000 cases of arsenic poisoning resulting from drinking beer which contained arsenic in the proportions of 2 to 4 mg/l.

He set limits for arsenic trioxide of 1 mg/l for solid food and 0.1 mg/l for liquid food. There are probably several reasons for his differentiation of limits for liquids and solids.

(1) Consumption of liquids is greater.

(2) Assimilation of arsenic from liquids is greater due to its being dissolved.

Other organizations which have set limits for drinking water are as follows:

World Health Organization (Geneva '58)	0.2 mg/l
European Standard (Geneva '61)	
Public Health Service of the U.S.A.	
Recommended Limit	0.01 mg/l
Mandatory Limit	0.05 mg/l
Argentina	0.1 mg/l

The Kettering Laboratory made a study of the therapeutic use of arsenicals, and concluded that a safe limit for arsenic in drinking water would be 0.2 mg/l for a long period and 1.0 mg/l for a short period (1 to 2 days), and that 0.3 mg/l for a long period would be toxic.[13]

COMMENTS RE RECOMMENDED LIMITS FOR ARSENIC IN DRINKING WATER

It is customary to set limits for exposure to carcinogens at extremely low levels, compared to those levels at which carcinogenic effects have been observed. This is because of the statistical way in which the population is affected by carcinogens generally. For instance, a few people only slightly affected by the air pollution in London, England, Los Angeles, California or a few light smokers may acquire cancer which might be attributed to these causes.

In view of the fact that only a minute minority of the cases of cancer can be attributed to any cause, it is reasonable to set an exceedingly low limit on the exposure to a known carcinogen. Because one recorded case of cancer, a typically arsenic type was attributed to taking Fowler's solution in an amount equivalent to 0.2 mg/l of arsenic for a period of 30 years (Appendix H, Case No. 141, Table H-1), it is reasonable to set an absolute maximum limit of 0.3 mg/l for all water supplies in the Yellowknife area, and to follow as much as possible the standards established by the U.S. Public Health Service.

COMMON LEVELS OF ARSENIC IN THE ENVIRONMENT[13]

groundwater	0 to 55 mg/l
surface water	0 to 80 mg/l
sea water	0.001 to 0.08 mg/l
food - fish	3 to 170 mg/l
plant	0.023 to 0.25 mg/l
air, urban	<0.01 to 0.63 µg/cu. meter
soil	0.03 to 0.25
urine	0.008 to 0.85 mg/l

BIBLIOGRAPHY

1. Oslo, A. et al. (1960 edition). The Dispensary of the United States of America, J.P. Lippincott Publishing Co., Philadelphia and Montreal.

2. Dilling, Walter J. (1944). The Pharmacology and Therapeutics of the Materia Medica, Cassell & Co., London and Toronto.

3. Grindley, J. (1946). Toxicity to Rainbow Trout and Minnows of Some Substances Known to be Present in Waste Water Discharges to Rivers, Annals of Applied Biology, Vol. 33.

4. Drill, Victor, A. (1958) Arsenic, Pharmacology in Medicine, Second Edition, McGraw Hill Book Co.

5. Monier-Williams, G.W. (1949) Trace Elements in Food, John Wiley and Sons. (162-172).

6. Robbins, Stanley, L. (1957) Textbook of Pathology. W.B. Saunders & Co. p. 203-4.

7. Hill, A.Bradford et al (1948) Mortality Experience in a Factory, British Journal of Industrial Medicine, Vol. 5.

8. Neubauer, O. (1947) Arsenical Cancer: A Review, British Journal of Cancer, Vol. 1.

9. Goldblatt, M.W. et al (1956) Industrial Carcinogenesis and Toxicology, Industrial Medicine & Hygiene, Butterworth & Co., London.

10. Mackenzie, J.K. (1931) Poisoning of Arsenic, Med. J. Australia, 317.

11. Goudey, R.F. (1943) The U.S. Public Health Service Drinking Water Standards--From the Operator's Viewpoint. J.A.W.W.A., V. 35, p. 1416.

12. Wyllie, J. (1937) An Investigation of the Source of Arsenic in a Well Water, Can. Public Health Journal, V. 28, p. 128.

13. (March/57) Physiological Aspects of Water Quality Criteria with Regard to Man, by Kettering Laboratory, College of Medicine, University of Cincinnati.

Photo No. 3

7 hr. 30 min. after deposit

Photo No. 4

18 hr. 20 min. after deposit

APPENDIX I

PHOTOS OF DYE

DEPOSITED 12:50 P.M., JULY 15, 1963

Photo No. 1

0 hr. 50 min. after deposit

Photo No. 2