MEDICAL SERVICES BRANCH

L.M. Black
Director General
Program Management

Date: 7.2.75.

À:
TO: 1. ~~M 18 -~~ information

noted
JB

REMARKS
REMARQUES:

RA
Smith

2. ~~M 16 -~~ for information and any follow-up via the N.W.T. Water Board.

Directeur général
Gestion des programmes

DIRECTION DES SERVICES MÉDICAUX

P.A. 850-5-X751

Government of Canada / Gouvernement du Canada

MEMORANDUM NOTE DE SERVICE

SECURITY - CLASSIFICATION — *DE SÉCURITÉ*	
OUR FILE — *N/RÉFÉRENCE*	150-5-4-N (N3)
YOUR FILE — *V/RÉFÉRENCE*	
DATE	January 31 1975

TO / *À*: Director General
Program Management
Medical Services Branch

ACTION | PA date | BF date
M ~~14~~ | 25/9/75
INFORMATION
M | M | M
M | M | M
M | M | M

FROM / *DE*: A/Programs Medical Officer
Northwest Territories Region

SUBJECT / *OBJET*: KAM LAKE - USE AS SEWAGE TREATMENT LAGOON

Attached is a copy of a review of the proposal of the City of Yellowknife to dump untreated sewage into Kam Lake (utilize Kam Lake as a sewage treatment lagoon).

This office was instrumental in raising objections to this project when it came to our attention and I believe was indirectly associated some years ago with the tentative approval of the same project.

However, in the interim ideas - and available legislation - have changed, making the proposal unacceptable on both public health and legal grounds.

7 FEB 75

R. D. P. Eaton, M.B., Ch.B., D.P.H.
A/Programs Medical Officer

(1) → ~~M18~~ info.

Enc.

(2) → M

Bill for your info, c any follow-up via the NWT Water Board.

JM.

3.7.2

KAM LAKE REVIEW

NORTHWEST REGION

ENVIRONMENTAL PROTECTION SERVICE

ENVIRONMENT CANADA

DECEMBER, 1974

Environment Canada | Environnement Canada

Environmental Protection | Protection de l'Environnement

1023, 10025 Jasper Avenue
Edmonton, Alta.
T5J 2X9

January 9, 1975

Mr. J.J. Eatock, P.Eng.
Regional Director
Northwest Region
Environmental Protection Service
Environment Canada
1023, 10025 Jasper Avenue
Edmonton, Alta.
T5J 2X9

Your file Votre référence

Our file Notre référence

4782-1

Dear Mr. Eatock:

Re: Letter of Transmittal - Kam Lake Review

As requested in your memorandum of September 30, 1974, I have convened a multi-disciplinary group for the purpose of reviewing the background and environmental implications of using Kam Lake as a sewage lagoon.

We reviewed the background of the use of Kam Lake, present wastewater characteristics, the limnology of Kam Lake and the effect of continuing sewage discharge into the lake.

The review has revealed that Kam Lake has intrinsic value from a variety of points of view including the presence of a significant fishery resource; recreational value and aesthetic value. The relationship of a number of these values to potential adjacent residential development has been recognized.

The review group concluded that the use of Kam Lake as a sewage lagoon is unacceptable from an environmental and public health point of view. Such use appears to contravene the spirit of the Fisheries Act as well as the Territorial health and environmental protection ordinances. It is contrary to the policy of the Environmental Protection Service as outlined in Policy and Planning Reports EPS-2WP-37-1.

Conceptually, it is possible to design, construct and operate a sewage treatment plant to protect the lake; however, it is highly probable that the cost of such a facility would be prohibitive. The level of treatment required to protect Kam Lake adequately would be very complex and expensive. It is probable that a less complex sewage treatment works in conjunction with a properly designed outfall to Great Slave Lake would meet the needs of Yellowknife.

A significant arsenic problem has been identified in Kam Lake; however the causes are being brought under control and it has been predicted that the lake will recover in approximately one or two decades.

It has been observed by the review group that to date there is only minor biotic impairment due to current sewage additions. However, the presence of arsenic is a pervasive issue and the proposed increase of sewage loading on Kam Lake will complicate the arsenic problem as well as causing classical symptons of organic and nutrient pollution.

Our review group has concluded the following:

1. The use of Kam Lake as a sewage lagoon is an unacceptable practice.

2. Addition of sewage or sewage effluent will produce accelerated eutrophication in Kam Lake and will result in the complication of the present arsenic problem.

3. The City of Yellowknife should investigate the feasibility of a sewage treatment plant to adequately protect Kam Lake.

4. The feasibility study should be based on allowing preservation and recovery of the lake, including projected city growth to 1990. Suspended solids, BOD, phosphorus and nitrogen loadings should be controlled to acceptable levels.

5. The feasibility study will likely reveal that the cost of providing treatment works to protect Kam Lake will be extremely high and other alternatives will have to be considered.

6. Any effluent discharge from the City of Yellowknife will be to a natural lake and the outfall should therefore be designed in such a manner to minimize acute toxicity, oxygen depletion and eutrophication effects.

I wish to acknowledge the contribution of the following individuals who participated in this review.

Dr. R.D.P. Eaton, National Health and Welfare, Edmonton
Dr. Gregg Brunskill, Freshwater Institute, Winnipeg
Mr. Mike Hardon, Environmental Protection Service, Yellowknife
Dr. Dave Lane, Environmental Protection Service, Edmonton
Mr. Pat Given, Environmental Protection Service, Edmonton
Mr. Jim Bell, Environmental Protection Service, Edmonton
Mr. Howard Chambers, Environmental Protection Service, Yellowknife

I would also like to acknowledge the foresight of Fisheries and Marine Service for doing the studies which made much of the data available for our review.

...Page 3

Also I would like to acknowledge the contribution of Dr. R.R. Wallace of EPS Yellowknife who made available some very recent information on heavy metal contamination of fish flesh and some equally new work done on arsenic in Kam Lake sediments with chemical analysis of the latter done by Dr. J. VanLoon of the University of Toronto. And especially I should acknowledge Mr. S.E. Hrudey of my staff for an excellent effort in editing this report.

If the review group may be of further service we would be pleased to respond.

Respectfully submitted,

Archie R. Pick

Archie R. Pick, P.Eng.
Head, Water Pollution Control Section
Environment Protection Service
Northwest Region

cc: C.A. Lewis
J.R. Marsh
P.M. Higgins

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LIST OF SYMBOLS AND DEFINITIONS

As^{+5}	arsenic with oxidation number of +5 (oxidized arsenic)
As^{+3}	arsenic with oxidation number of +3 (reduced aresenic)
BOD_5	5 day, 20°C biochemical oxygen demand
C	Concentration of substance at time t
C_o	initial concentration of substance
^oC	degrees celsius
cm	centimeter
COD	chemical oxygen demand
e	base of natural logarithm
E_h	oxidation-reduction potential with respect to the hydrogen electrode
°F	degrees Fahrenheit
ft	feet
g	gram
imp gal	imperial gallon
in	inches
kg	kilogram
km	kilometer
l	liter
lb	pound
m	meter
m^3	cubic meters
mg	milligram
mg/l	milligram per liter, (parts per million)
mV	millivolts
ND	not detected
pH	negative logarithm of hydrogen ion concentration in moles/liter

Q	Average lake outlfow rate
t	time
t_o	theoretical retention time of lake
TSS	total suspended solids
ton	British ton, 2,000 lb
tonne	1 metric ton, 1000 kg
μ	micron
μg	microgram or 10^{-6} grams
μmho/cm	micro mho per centimeter, units of conductance
wt	weight
yr	year
$<$	less than

SUMMARY

The Environmental Protection Service has coordinated a review of the proposed use of Kam Lake as a sewage lagoon for the City of Yellowknife. The background of the use of the lake, present wastewater characteristics, the limnology of the lake and effect of direct sewage discharge into the lake were reviewed. The review revealed that Kam Lake has intrinsic value from a number of points of view including the presence of a significant fishery resource; recreational values and aesthetic values. This latter value was recognized in 1971 when the use of Kam Lake for a sewage lagoon was recognized as a limitation in residential development for the city. Further, in seeking approval, the City indicated the site would be remote from any residential development.

The review group concludes that the use of Kam Lake as a sewage lagoon is unacceptable from an environmental and public health point of view. Such use appears to contravene the spirit of the Fisheries Act as well as the Territorial Public Health Ordinance and Environmental Protection Ordinance. It is contrary to the policy of the Environmental Protection Service as outlined in Interim Guidelines for Wastewater Disposal in Northern Canadian Communities - EPS Policy and Planning Report EPS-2WP-74-1.

It is possible to design, construct and operate a sewage treatment plant to protect Kam Lake; however it is highly probable that the cost of such a facility would be prohibitive. It has been estimated that in order to adequately treat the City of Yellowknife sewage at 1990 loads, efficiencies would have to exceed 99 percent removal for BOD, suspended solids, phosphorus and nitrogen, respectively. It is probable that a less complex sewage treatment works, in conjunction with a properly designed and constructed diffuser to Great Slave Lake, would meet the needs of Yellowknife.

A significant arsenic problem has been identified in Kam Lake; however, the causes are being brought under control and it has been predicted that the lake will recover in approximately two decades. Discharge of raw sewage to Kam Lake at the predicted rates will result in nutrient enrichment with subsequent oxygen depletion. Probably this typical pattern of eutrophication will be complicated by conversion of the arsenic present in the lake from its present highly oxidized to a more toxic reduced form.

CONCLUSIONS AND RECOMMENDATIONS

1. Kam Lake has intrinsic value from a number of points of view, including fisheries, recreational and aesthetic values.
2. The use of Kam Lake as a sewage lagoon is unacceptable to the Environmental Protection Service and the Department of National Health and Welfare.
3. It is possible to design, construct and operate a sewage treatment plant to adequately protect the lake; however, due to the level of treatment that would be required the plant would be very expensive to build and operate. It is estimated that at 1990 sewage loads sustained efficiencies of BOD_5, suspended solids, phosphorus, and nitrogen removal would need to exceed 99% respectively.
4. A significant arsenic problem has been identified in Kam Lake; however, the causes appear to be under control or are being brought under control. This could result in recovery of the lake in approximately two decades.
5. The Review Group considered a number of alternatives and is of the opinion that probably discharge to Great Slave Lake, after treatment, through a properly designed and located long outfall would be acceptable wastewater treatment for the City of Yellowknife.
6. Proper records relating to water consumption, sewage discharge and strength should be kept by the City of Yellowknife.
7. The Review Committee is of the opinion that basic research on lakes adjacent to Yellowknife, and other growing communities, should be encouraged. Further research into the processes of eutrophication in Arctic and Sub-Arctic regions should be initiated.
8. Research should be initiated into the oxidation and reduction of arsenic rich mine wastes and their relationship to aquatic ecosystems in lakes and streams of the Arctic and Sub-Arctic regions.

1 INTRODUCTION

1.1. Background

1.1.1 Historical Information. During 1947 and 1948 the Department of Public Works established the Niven Lake sewage disposal system for the Town of Yellowknife. Prior to 1965, a small detention pond was constructed at the sewage forcemain outlet to Niven Lake. In 1965, the Department of National Health and Welfare indicated that Niven Lake effluent was adequate to protect water supplies from Yellowknife Bay, provided those supplies were disinfected.

In 1970, Makale, Holloway and Associates Ltd., the city planners for Yellowknife, developed a 20-year plan. They recommended expansion of the City in a northerly direction toward Stock Lake and Giant Mine including the Niven Lake area. This decision, coupled with a study by the Public Health Engineering Division, Department of Fisheries and Forestry (Grainge, 1971) indicating very poor wastewater treatment by Niven Lake, suggested to the City that abandonment of Niven Lake as a sewage lagoon was necessary.

1.1.2 Proposal for Sewage Disposal to Kam Lake. After the Makale, Holloway study, the City commissioned an engineering study of sewage by Stanley Associates Engineering Ltd. (Stanley Associates Ltd. 1971). This study examined various alternatives for treatment systems at four sites: Niven Lake; Yellowknife Bay; Pud Lake and Kam Lake. The least expensive alternative was the Kam Lake disposal system. Selection of the Kam Lake site was based on the following provisions, which are extracted from the consultant's report:

- i. "The area surrounding the Lake is not contemplated for development in the foreseeable future....."
- ii. "Treatment must be adequate to prevent occurrence of nuisance or health hazards, and in addition, should be such that no irreversible changes were wrought to the Lake...."
- iii "..., it might be possible and worthwhile at some time in the future to overcome the arsenic pollution now in Kam Lake and thus create new value for the Lake and its environs as a development area."
- iv. "Provision for advanced treatment as may be required or desirable in the future to permit its reclamation for development purposes....."

Although the above provisions were given, the study did not follow them up by determining the degree of treatment required, before disposal into Kam Lake in order to maintain water quality which would allow for possible future reclamation. The specification of these requirements would have required a biological and limnological study of Kam Lake.

1.1.3 Approval of Kam Lake Proposal.

1.1.3.1 Public Health Engineering Division Approval. On April 19, 1971, the Government of the Northwest Territories requested comments on the proposed Kam Lake sewage disposal system from the Public Health Engineering Division, Department of Fisheries and Forestry.

The request was forwarded to the Chief Medical Health Officer, Department of National Health and Welfare, who replied on April 30, 1971 stating that Kam Lake was unfit for water consumption and swimming because of the arsenic levels present. However, if Kam Lake was used for a sewage lagoon, it would not be possible to have any recreational activities in the area. It was noted by the Public Health Engineering Division that irreversible changes would occur in the lake.

The Public Health Engineering Division indicated the following to the City of Yellowknife at the conclusion of a report dated August 1971 (Grainge 1971).

> "This office concurs with this recommendation (Kam Lake disposal with anaerobic ponds), except that any additional treatment required should not necessarily be restricted to anaerobic lagoons if a monitoring program indicates the need for more adequate treatment. The low cost proposal is especially attractive in view of the higher capital and operating costs of any alternative sewage works, and the fact that there are more urgent problems in other areas of the Northwest Territories."

After the Stanley Associates report, the City employed Reid, Crowthers and Partners Ltd. to do the actual construction design. On August 17, 1971, the Public Health Engineering Division indicated the following to Reid, Crowther and Partners with respect to the City of Yellowknife - sanitary sewer outfall:

> "We have studied the plans and find that they meet the requirements for the Federal Water Pollution Control and Abatement Program and the Public Health Ordinance of the Northwest Territories."

1.1.3.2 Department of Indian Affairs & Northern Development. It was determined by the Public Health Engineering Division in October 1971, that the Regional Director of Resources, Department of Indian Affairs and Northern Development disagreed with the use of Kam Lake as a sewage oxidation pond. However, since the system had to be licensed under the Northern Inland Waters Act which is administered by the Department of Indian Affairs and Northern Development, the Public Health Engineering Division expected that the proposal would be subject to review by that department.

On December 8, 1971, the Public Health Engineering Division forwarded their report of August, 1971 which included Division approval of the Kam Lake disposal system to the Department of Indian Affairs and Northern Development.

1.1.3.3 Government of Northwest Territories. In November, 1972, the Mayor of the City of Yellowknife forwarded a document (Reid, Crowthers & Partners Ltd. 1972) to the Northwest Territories Government requesting approval and funds for the diversion of sewage from Niven Lake to Kam Lake. This document included the recommendations contained in the Stanley report and the approval of the Public Health Engineering Division.

The following is an excerpt from that document:

> "The City's engineering studies (Stanley Report) indicated that sewage disposal facilities be located at the Kam Lake site, located to the southwest of the developed area, as it was anticipated that this location would be remote from any likely residential development."

Based upon this proposal, approval by the Government of the Northwest Territories followed with the requested monies for the construction. It is believed, that the approval within the Government of the Northwest Territories was based only on an administrative appraisal of the proposed system and did not include a technical appraisal. This was valid since the Public Health Engineering Division approval was included in the proposal.

1.1.3.4 Recent Developments. In preparation for discussion of licensing for the City of Yellowknife, under the Northern Inland Water Act, the Environmental Protection Service, Yellowknife, enquired into the use of Kam Lake as a sewage disposal site. From this investigation the NWT District Manager, Environmental Protection Service wrote to the Chairman of the Northwest Territories Water Board on May 6, 1974 suggesting a meeting with all parties concerned to discuss the possible contravention of the Northwest Territories Public Health Ordinance, uncertainty of zoning in the Kam Lake area and review the rationale for using Kam Lake as a sewage lagoon. The reply stated that only upon submission of a water license application could the development be reviewed under the auspices of the Northwest Territories Water Board and suggested that any meeting regarding the development should be called by the administrators of the Northwest Territories Health Ordinance.

On July 29, 1974, the Environmental Protection Service informed the Northern Region, Medical Services of the Department of National Health and Welfare of the concerns regarding sewage disposal into Kam Lake.

On August 9, 1974, the Director of Medical Services wrote to the Government of the Northwest Territories indicating the concerns related to the proximity of the sewage disposal system to existing buildings. The following is quoted from that letter:

> "It is therefore recommended, that the City of Yellowknife be advised that approval will not be given to the use of Kam Lake as a sewage disposal area and that they should be advised to seek an alternative disposal site."

Subsequent to this, an exchange of letters between the Government of the Northwest Territories and the Director of Medical Services took place.

On August 7, 1974, the News of the North reported that the Mayor of Yellowknife "would like to see a sewage treatment plant installed and operating in Yellowknife, as soon as possible."

During the summer of 1974, the Government of the Northwest Territories released land in the vicinity of Kam Lake to the City of Yellowknife. A residential subdivision for 7,000 people is now planned for the Kam Lake vicinity.

On September 25, 1974, the City of Yellowknife requested a review by the Environmental Protection Service.

1.2 Regulatory Requirements.

As a statement of principle, the use of existing inland waters as lagoons for the treatment of raw sewage is undesirable and unacceptable to Environment Canada as stated previously (Environmental Protection Service, 1974). In addition to this policy, there are several regulations covering sewage disposal which are administered by various authorities.

1.2.1 Northwest Territories - Public Health Ordinance. This ordinance and its regulations are administered by the Department of National Health and Welfare. The pertinent section to this review is 29(b) of the regulations which states, "Every waste disposal ground shall be located at least 500 yards from any building used for human occupancy or for the storage of foods."

1.2.2 Northwest Territories - Environmental Protection Ordinance. This Ordinance and its regulations are administered by the Government of the Northwest Territories. The pertinent section is 6(1) which states that, "No person shall discharge or permit the discharge of any contaminant into the environment that:

(a) causes or contributes or is likely to cause or contribute to substantial impairment of the quality of the environment and/or

(b) adversely affects or is likely to adversely affect the health, safety or comfort of any person."

1.2.3 Northern Inland Waters Act. This Act and its regulations are administered by the Department of Indian Affiars and Northern Development. The pertinent sections are 2(2), 6(1), 10(2) and 10(3). Basically, this Act requires the user of water to obtain a license which imposes conditions as to the quality of the waste water when it is released back into the environment.

1.2.4 Fisheries Act. This Act and its regulations are administered by the Department of the Environment. The pertinent sections are 33(2) and 33(12) which require that no person shall deposit a deleterious substance into waters frequented by fish except as provided for by regulations specifying allowable discharges of deleterious substance.

1.3 City Planning.

1.3.1 Population. Population projections for Yellowknife are difficult to make. The three basic population contributors, the gold mines, federal and territorial governments along with the Mackenzie Valley Pipeline and their plans will reflect the growth patterns of Yellowknife for some time to come.

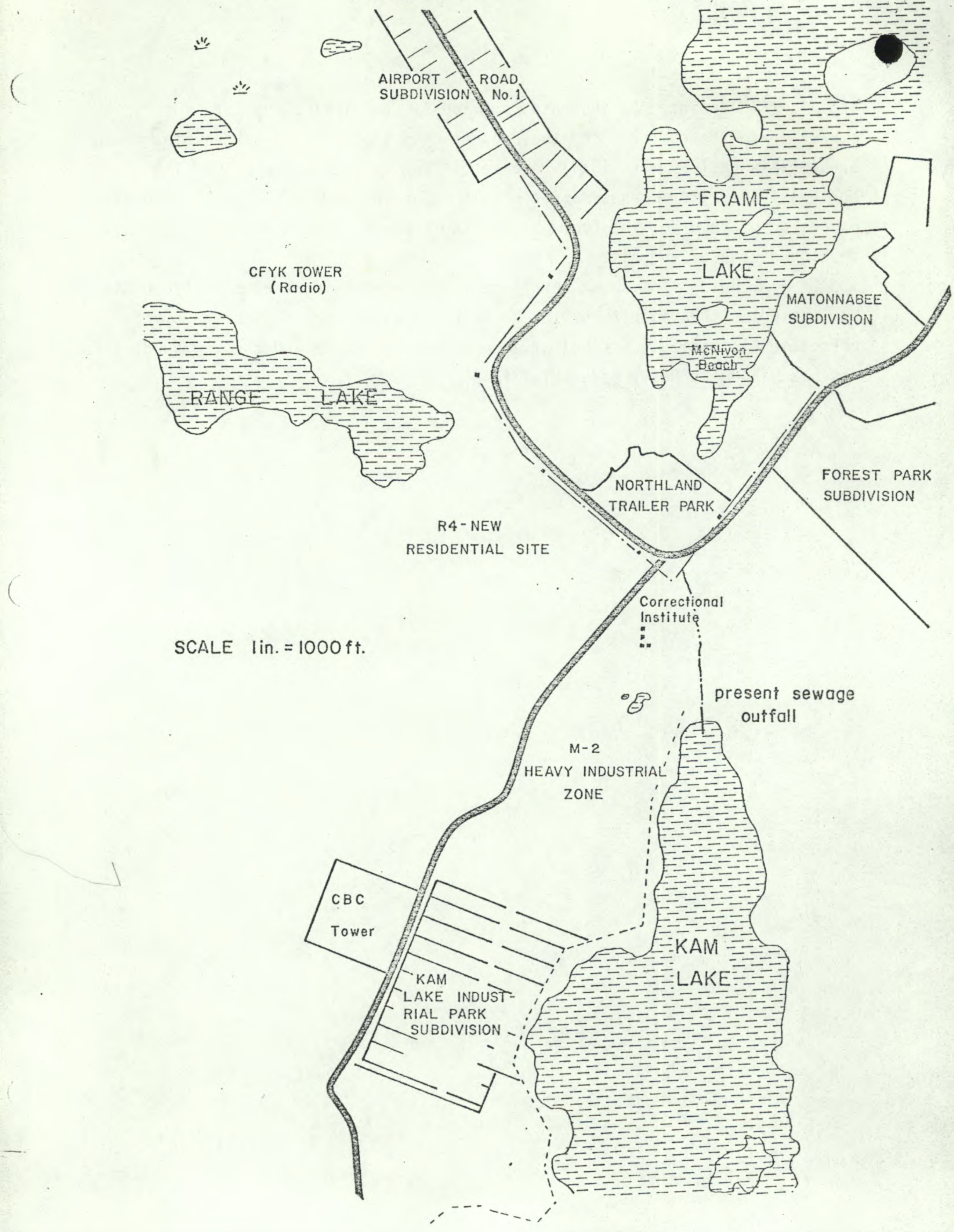
Present population and predictions are (Olszamowski, 1974):

Year	Population
1970	6,500
1975	9,800
1980	12,300
1985	14,100
1990	16,300

1.3.2 Planning. As indicated previously, original plans were for expansion to the northeast of the present city in the Niven Lake - Stock Lake area. This past summer (1974) release of land by the Government of the Northwest Trerritories has resulted in a major shift with the next residential expansion planned for the Frame Lake - Kam Lake area south of the presently developed area of the city.

1.3.3 Zoning. As shown in Figure 1, the new residential site (Zone R4) will be located in the vicinity of the Northland Trailer Park and northwest of the correctional institute. A buffer zone between Kam Lake and the new subdivision has been zoned as heavy industrial (M-2).

FIGURE 1


AIRPORT SUBDIVISION
ROAD No. 1
FRAME LAKE
CFYK TOWER (Radio)
MATONNABEE SUBDIVISION
McNivon Beach
RANGE LAKE
NORTHLAND TRAILER PARK
FOREST PARK SUBDIVISION
R4 - NEW RESIDENTIAL SITE
Correctional Institute
SCALE 1 in. = 1000 ft.
present sewage outfall
M-2 HEAVY INDUSTRIAL ZONE
CBC Tower
KAM LAKE
KAM LAKE INDUSTRIAL PARK SUBDIVISION

2 YELLOWKNIFE SEWAGE CHARACTERISTICS

2.1 Chemical Characteristics

Based on data collected from May 29 to September 10, 1974, at the Environmental Protection Service Wastewater Treatment Demonstration Project in Yellowknife, the raw sewage for the City of Yellowknife is characterized as shown in Table 1.

Wastewater characteristics were subject to considerable variation during the monitoring period. For example, the five day biochemical oxygen demand (BOD_5) ranged from 40 to 360 mg/l, chemical oxygen demand (COD) ranged from 80 to 525 mg/l and total suspended solids (TSS) ranged from 40 to 355 mg/l. Only pH remained fairly constant, ranging between 6.7 and 7.0.

It appears that infiltration and sump pump operations greatly affect the sewage characteristics; however, insufficient data on flow rates are available to enable quantification of these effects.

Data on the portion of Yellowknife sewage currently being discharged to Kam Lake has been gathered by the Fisheries and Marine Service and is shown in Table 2.

2.2 Sewage Flows

Data on sewage flow rates for the City of Yellowknife are quite limted since no measuring and recording devices are used.

In December, 1973, estimates were made of the sewage flow by Reid, Crowther and Partners Ltd. of Edmonton. The quantity of sewage flowing to the lagoon and thence to Niven Lake was estimated to be approximately 3,200,000 l/day (700,000 imp gal/day). This estimate was based upon the number of pumping cycles per day and the displaced volume per cycle at the sewage lift station over a two week period. Since the population served by the sewage system was roughly 7,000 people, according to the City Works Department, the sewage flow was about 455 l per capita per day (100 imp gal per capita per day).

At that time an estimate was also made on the sewage flow into Kam Lake based upon water consumption data from the contributing areas, namely the Northland Trailer Court, the Yellowknife correctional Institute and the new City Garage. The estimated quantity of sewage was approximately 120,000 l/day (27,000 imp gal/day).

2.3 Waste Loading

Based upon the preceding sewage flow rates and chemical characteristics presented in Tables 1 and 2, the total waste loadings were estimated and are summarized in Table 3.

TABLE 1

RAW SEWAGE CHARACTERISTICS FOR CITY OF YELLOWKNIFE

PARAMETER	AVERAGE VALUE
Biochemical Oxygen Demand (5 day)	165 mg/l
Chemical Oxygen Demand	285 mg/l
Total Suspended Solids	175 mg/l
pH	6.9
Total Alkalinity	115 mg/l as $CaCO_3$
Total Phosphorus	3.3 mg/l as P

TABLE 2

CHARACTERISTICS OF RAW SEWAGE DISCHARGED TO KAM LAKE
(1972 - 1974)

PARAMETER	MEAN	RANGE
Specific Conductance (umhos/cm at 26°C	526 (15)*	168-1600
pH	7.2(38)	6.4-7.7
Calcium mg/l	40.4(35)	6.92-440
Magnesium mg/l	9.5(35)	0.984-56.4
Sodium mg/l	47.8(35)	12.9-437
Potassium mg/l	8.58(35)	4.13-20.0
Bicarbonate mg/l	164 (37)	46.9-255
Sulphate mg/l	49.3(34)	4.22-216
Chloride mg/l	31.3(36)	<0.32-254
Total Dissolved Phosphorus mg/l	2.63(32)	0.611-10.6
Particulate Phosphorus mg/l	.55(18)	<0.002-15
Total Dissolved Nitrogen mg/l	7.0(37)	0.17-33.5
Particulate Nitrogen mg/l	2.5(31)	0.13-13.8
Siliac mg/l	4.4(33)	0.61-18.8
Total Dissolved Arsenic mg/l	-	ND-3.4
Particulate Arsenic mg/l	-	ND-0.85
Particulate Carbon mg/l	30.6(27)	10.8-112
Dissolved Organic Carbon mg/l	16.1(7)	11.8-22.3
Iron mg/l	0.69(18)	0.11-3.4
Manganese mg/l	0.11(11)	<0.01-0.29
Lead mg/l	0.003(16)	<0.002-0.006
Cadmium mg/l	0.003(5)	<0.001-0.010

*Note: The number in parenthesis behind the mean value is the number of samples analysed.
ND = not detected

TABLE 3

ESTIMATED 1973 WASTE LOADS FROM YELLOWKNIFE

PARAMETER	INTO NIVEN LAKE	INTO KAM LAKE	TOTAL
Flow Rate			
l/day	3,200,000	120,000	3,300,000
(Imp gal/day)	(700,000)	(27,000)	(730,000)
Biochemical Oxygen Demand (BOD_5)			
kg/day	550	20	570
(lb/day)	(1,200)	(45)	(1,200)
Chemical Oxygen Demand			
kg/day	910	35	950
(lb/day)	(2,000)	(77)	(2,100)
Total Suspended Solids			
kg/day	550	21	570
(lb/day)	(1,200)	(47)	(1,200)
Total Phosphorus			
kg/day	11	0.4	11
(lb/day)	(23)	(.90)	(24)
Total Nitrogen			
kg/day	30	1.2	31
(lb/day)	(67)	(2.6)	(70)

TABLE 4

ESTIMATED 1990 WASTE LOADS FROM YELLOWKNIFE

(POPULATION 16,300)

PARAMETER	TOTAL
Flow Rate	
l/day	7,300.000
(Imp gal/day)	(1,600,000)
Biochemical Oxygen Demand (5 day)	
kg/day	1,200
(lb/day)	(2,600)
Chemical Oxygen Demand	
kg/day	2,100
(lb/day)	(4,600)
Total Suspended Solids	
kg/day	1,300
(lb/day)	(2,800)
Total Phosphorus	
kg/day	23
(lb/day)	(50)
Total Nitrogen	
kg/day	70
(lb/day)	(150)

It is concluded that the proposal to discharge all raw sewage from Yellowknife into Kam Lake would result in the total loadings, shown in Table 3, being imposed immediately upon Kam Lake.

Assuming the population of Yellowknife reaches 16,300 by the year 1990, and at sewage characteristics and per capita flow rate are unchanged, then the average daily sewage load from Yellowknife would be as shown in Table 4.

It should be noted that the preceding estimates were based upon very limited data. In particular, more accurate flow rate data, such as could be obtained from a Parshall flume and recorder over a minimum of one year operation, would be desirable. Also, measurements of flow rates and sewage characteristics were performed at different times of the year; it would be desirable to have similtaneous measurements of these to enable accurate calculation of the resulting daily BOD_5, suspended solids, phosphorus and nitrogen loads. With this data, a better assessment of the required treatment and the effects on the receiving water body could be made.

3 KAM LAKE LIMNOLOGY

3.1 Physical Characteristics

3.1.1 Bathymetry. The basic physical features of Kam Lake are shown in Table 5 and Figure 2. The lake has three deeper basins that probably collect most of the pelagic suspended sediments. Shallow areas are infrequent in the lake, with the exception of small bays and the area below the channel from Grace Lake (Figure 2). The north end of the lake, at the site of sewer outfall, has a gentle slope of 18 cm/m (2.2 in/ft) to a depth of 4 m (13 ft.). A steeper slope of 25 cm/m (3.0 in/ft) occurs 800 m (2,260 ft) south of the site of sewer inflow, which ends in a relatively flat bottomed area at a depth of 12 m (39 ft).

3.1.2 Hydrology. A water budget for Kam Lake is being attempted; however, the present data are at best order of magnitude estimates (Table 5). Based on the present volume of the lake, and crude estimates of annual outflow, it appears that the lake replaces its volume at a minimum of once every four years. Efforts to estimate other parameters of the hydrological budget are hampered by difficulties in estimating (a) watershed area of Kam Lake; (b) evaporation and evapotranspiration; and (c) groundwater flow. Because of poor drainage in the area, it is difficult to estimate the drainage area boundary of the lake from aerial photographs. Data from the Yellowknife airport indicate that pan evaporation was three times greater than measured precipitation in the recent past, which implies that evaporative concentration of dissolved salts could be a major factor in controlling the chemical composition of some lakes in this area. During winter, little or no flow occurs at the natural inlets and outlets of Kam Lake. Previous to 1974-75 water and sediment-slush ice slurries flowed on to Kam Lake ice from Pud Lake during winter.

3.1.3 Physical Limnology.

3.1.3.1 Temperature. Kam Lake is thermally stratified in summer and weakly stratified in winter, with periods of isothermal mixing for a brief period after ice melt in spring, and for several weeks in fall. Under winter ice, the lake water cools to <1°C (34°F) to a depth of 6-8 m (20-26 ft). Near the bottom, water temperatures are between 1° and 2°C (33.8"F and 34.6°F) during winter. Ice cover occurs in October and melts in May. After ice melt, the surface waters of the lake warm rapidly to 15-20°C (59°F-68°F) by mid-June, with a thermocline developing at 5-8 m (16-26 ft) depth. During the months of June through August, the lake is thermally stratified with an epilimnic volume of about 10×10^6 m^3 (8,100 acre-ft) and a hypolimnic volume of 1.7×10^6 m^3 (1,400 acre-ft). Surface temperatures exceed 20°C (68°F) in mid summer (late June - early

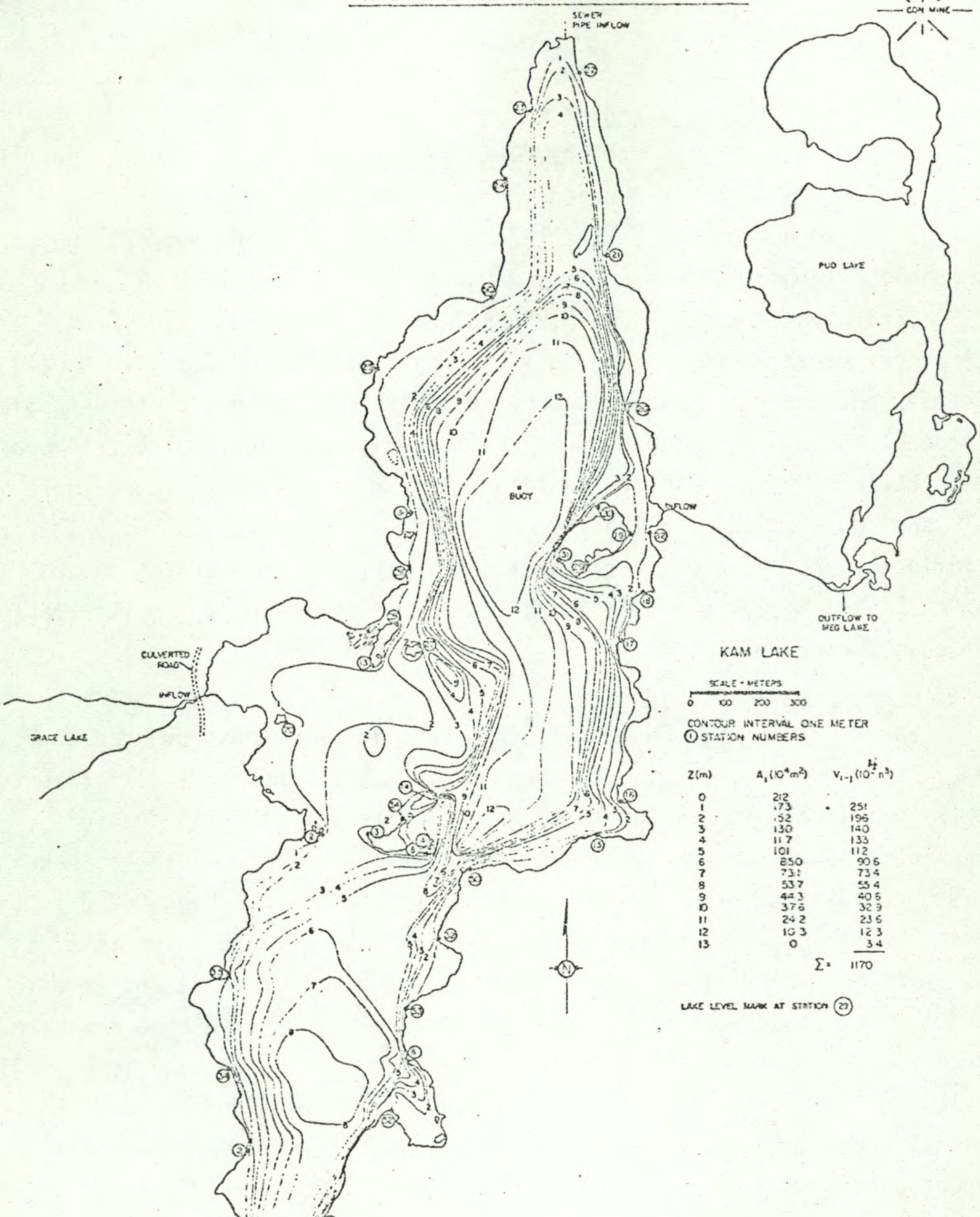
TABLE 5

MORPHOLOGICAL AND HYDROLOGICAL DATA FOR KAM LAKE, N.W.T.

Surface area (A_o)	212×10^4 m^2 (2.28×10^6 ft^2)
Volume (V)	11.7×10^6 m^3 (413×10^6 ft^3)
Mean depth ($\bar{Z}$)	5.5 m (18 ft)
Maximum depth (Z_{max})	12.8 m (42 ft)
Annual Precipitation	200-360 mm (40% as snow) (7.9-14 in)
Annual outflow (Q_o)	3.1×10^6 m^3/yr (109×10^6 ft^3/yr)
Theoretical Flushing rate ($= \frac{V}{Q_o}$)	3.8 years

FIGURE 2

PHYSICAL FEATURES OF KAM LAKE



Z(m)	A_i ($10^4 m^2$)	V_{i-1} ($10^4 m^3$)
0	212	
1	173	251
2	152	196
3	130	140
4	117	133
5	101	112
6	850	906
7	731	734
8	537	554
9	443	406
10	376	329
11	242	236
12	103	123
13	0	34
	$\Sigma =$	1170

August). In late August and September, this thermal stratification breaks down and the lake is isothermally mixed at temperatures from 8°C (46°F) to around 1°C (34°F) until ice cover in October. There is an unexplained thermal anomaly at 10-12 m (33-39 ft) depth in June and July. During this time, water temperatures at the bottom are between 2°C and 4°C (35.6°F and 39.2°F), which is less than the temperature of maximum density.

3.1.3.2 Light Penetration. Water transparency of Kam Lake varies from 1.3 m (4.3 ft) Secchi visibility (during algal blooms in spring and fall) to 4m (13 ft) in mid summer and under winter ice. Based on this information, photosynthetic growth probably occurs to a depth of 6-8 m (30-26 ft) during the ice-free season. Light penetration through lake ice in late fall and early spring (when there is little snow on the ice) is likely significant, since algal chlorophyll concentrations increase, and supersaturation of oxygen occurs during these periods. As soon as snow accumulates on the ice, light penetration into lake water is greatly reduced.

3.2 Chemical Characteristics

3.2.1 Water Chemistry. Chemically, Kam Lake is anomalous compared to adjacent lakes (Frame, Grace, Stock, Long, Fault Lakes) and to similar lake types 15-25 km(9-16 miles) north and northeast of Yellowknife. This is due to a history of atmospheric and surface water influx of mine wastes into Kam Lake from 1940 until the present. In addition, raw sewage has been added to the lake since 1972. The chemical composition of Kam Lake surface water is given in Table 6, which indicates that calcium, sodium, sulphate, chloride and arsenic are found in much higher concentrations in Kam Lake then in nearby Grace Lake. The source of the high concentrations of these elements in Kam Lake is a small stream flowing from Pud Lake, the tailings pond of Cominco Consolidated Mine. North of Yellowknife and just east of the northern part of Prosperous Lake, lakes occur on the same bedrock as Kam Lake. Two of these lakes (Likely and Homer Lakes) were sampled and it was found that arsenic, sodium, sulphate and chloride concentrations were two orders of magnitude less than in Kam Lake. This indicates clearly that the high concentration of the above mentioned elements in Kam Lake does not result from natural weathering of Greenstone Belt rocks.

Concentrations of the elements in Kam Lake listed in Table 6 vary considerably over the seasons, and also vary from year to year. Most elements do not vary greatly with depth in the lake, although some elements increase in concentration slightly near the bottom muds. For example, specific conductance varies from 2,500 to 3,500 umhos/cm at 25°C (77°F) under spring ice, to 1,200 to 1,500 umhos/cm in July.

Nutrient concentrations in Kam Lake are relatively high for the region. The addition of raw sewage has had an unknown effect on the nutrient makeup of the lake. When nutrients (such as nitrogen and phosphorus) are added to a lake, they are quickly taken up by algae, which consequently increase their growth rates and abundance. Thus, it is not possible to estimate the effect of past sewage addition on Kam Lake without measurements of algal production (which is currently unavailable).

During periods of isothermal mixing in spring and fall, Kam Lake waters are usually at or near oxygen saturation. During algal blooms at these times of the year, oxygen is frequently present in supersaturation as a result of algal photosynthesis. During midsummer thermal stratification, oxygen concentrations often decline to less than 50 percent of saturation in the 10 to 12 m (33-39 ft) depth stratum of the lake. During June, July and August in 1972 and 1973, oxygen concentrations fell below 2 mg/l at 10-12 m (33-39 ft) depth, and 0.0 mg/l was observed in late July and early August of those years. Under winter ice, the deeper parts of the lake seldom have oxygen concentrations less than 60 percent of saturation. During late winter and early spring, oxygen depletion to less than 50 percent of saturation occurs.

Dissolved arsenic (As^{+5}, as arsenate) in the water column at a sample station at maximum depth varies from 2.3 to 6.7 mg/l. Since 1971, it appears that there was a slight decline in the total mass of arsenic in the lake, from 40 tonnes (44 tons) to 37 tonnes (40.7 tons) in 1974. Arsenic in particulate form (in algal cells and particulate organic/inorganic matter) is usually very low in concentration, but is easily detected during periods of algal blooms in spring. Based on outflow data of poor reliability it is estimated that losses of arsenic from Kam Lake occur at the outlet (3-5 tonnes/year) and by sedimentation to the bottom muds (1-2 tonnes/year, based on sediment trap data). There is little variation of concentrations of total dissolved arsenic or particulate arsenic with depth.

TABLE 6

CHEMICAL COMPOSITION OF KAM LAKE AND GRACE LAKE SURFACE WATERS

JULY 1974

Parameter	Kam Lake	Grace Lake
Specific conductance (umhos/cm at 25°C)	2300	120
pH	7.8-8.3	7.7-8.2
Calcium mg/l	240-320	15
Magnesium mg/l	21	4.6
Sodium mg/l	140-180	4.4
Potassium mg/l	10	2.0
Bicarbonate mg/l	104	49-61
Sulphate mg/l	326	18-22
Chloride mg/l	500-640	7.5-8.2
Total Dissolved Phosphorus mg/l	0.006-0.043	0.003-0.015
Particulate Phosphorus mg/l	0.009-0.090	ND-0.011
Total Dissolved Nitrogen mg/l	0.28-2.1	0.22-0.34
Particulate Nitrogen mg/l	0.28-.70	0.07-0.13
Silicon mg/l	1.4-2.0	0.06-0.14
Total Dissolved Arsenic mg/l	2.6-3.4 (All as A_S^{+5})	ND-0.015 (All as A_S^{+5})
Particulate Arsenic mg/l	ND-.013	ND
Particulate Carbon mg/l	0.96-1.8	0.42-0.96
Dissolved Organic Carbon mg/l	12-24	8.4-12
Iron mg/l	5.6-45	ND-5.6

ND - not detected

Based on selected data from the period 1971 to 1974, a rough mass budget for Kam Lake arsenic supply and loss in Kam Lake can be proposed. Considerably more hydrological and chemical information is required to verify this model. There exists in Kam Lake waters about 40 tonnes (44 tons) of dissolved arsenic. During 1973 and 1974, 3-5 tonnes (3.3-5.5 tons) of dissolved arsenic left the lake in outflow waters annually. For each four year period of flushing of the lake volume, the dissolved arsenic concentration would be reduced by 63% if there were no inflow of arsenic to the lake in the future. This is calculated from the theoretical equation for concentration decrease with outflow from a completely mixed water volume with no parameter mass inflow (O'Connor, 1968):

$$C = C_o e^{-t\,(1/to)}$$

Where: C = Concentration of arsenic at any time t (mg/l)

C_o = Initial concentration of arsenic (mg/l)

t = Time (years)

t_o = Theoretical flushing time (volume/outflow)

e = Base of natural logarithms

This indicates that dissolved arsenic in Kam Lake would be reduced to approximately 0.015 mg/l (the maximum background level in Grace Lake) in 21 years. However, there are influxes of arsenic into the lake from the atmosphere, the lake sediments, and possibly from surface and subsurface flow from Pud Lake and it is difficult to quantify these inputs. Atmospheric arsenic input is thought to be relatively low, and could be decreased further by improved technology. Surface and subsurface flow from Pud Lake to Kam Lake could be essentially stopped by various technological improvements in diking and operation of the tailings pond (Roy et al, 1973). The flux of arsenic from lake sediments to Kam Lake water is unknown and cannot be estimated at this time.

Cyanide (CN) concentrations in the Pud Lake inflow to Kam Lake are just barely detectable (0.002 mg/l) and cyanide could not be detected in Kam Lake open water in 1971 (Berube et al, 1972).

3.2.2 Sediment Chemistry. Deep water Kam Lake sediments are composed of 36% clay, 57% silt, 1% sand and 6% organic matter. There is about 52 mg organic carbon/g dry wt., 3.9 mg nitrogen/g and 1.2 mg phosphorus/g in the surface 10 cm (4 in) of these deep water sediments.

Table 7 gives the concentrations of arsenic in the particles of sediment and in the interstitial water from the sediment at different sediment depths from a core at the maximum depth station (Figure 2). It is apparent that there is a large reservoir of arsenic in the sediment particules at sediment depths of 20-36 cm (7.9-14 in). Since the deep waters of Kam Lake are usually oxygenated, the surface sediment (0-12 cm, 0-5 in) interstitial water arsenic forms are those of oxidized arsenic (As^{+5}). Deeper in the sediment, however, little or no oxygen is found, and the arsenic is found largely as the reduced form (As^{+3}).

At water depths of 1 m(3.3 ft) and 4 m (13.1 ft) near the shores of Kam Lake, arsenic in sediment particles and interstitial water was much lower in concentration and was all in the oxidized form (As^{+5}). At water depths greater than 8 m (26 ft) arsenic chemistry was similar to that shown in Table 7.

As arsenic is flushed out of the lake according to the proposed mass budget, some of this sedimentary arsenic will diffuse into the overlying lake water. It is not known how important this flux might be, nor is it easy to estimate the chemical state or valence of arsenic derived from the lake sediments. Further work by the Fisheries and Marine Service is planned to study the flux of arsenic from sediment core samples.

It seems likely that low oxygen concentrations or anaerobic conditions would greatly accelerate the reduction of As^{+5} to As^{+3} and would likely provide conditions for the growth of micro-organisms that produce methylated forms of arsenic (Wolfe, 1971; McBride and Wolfe, 1971).

3.3 Biological Characteristics

3.3.1 Aquatic Flora. Based on the species and abundance of algae that occur in Kam Lake, the high chlorophyll concentration observed during algal blooms, and the abundance of zooplankton, the Kam Lake water column is tentatively regarded as a relatively fertile (meso/eutrophic) lake. High growth rates of planktonic algae, in spring, fall and under clear ice, results in oxygen supersaturation and marked changes in water transparency and colour. Planktonic organisms apparently accumulate very little arsenic from the lake water, since particulate arsenic in lake water is low or undetectable (Table 6). During algal blooms, however, larger amounts of arsenic are found in the suspended material.

TABLE 7

CHEMISTRY OF KAM LAKE PROFUNDAL SEDIMENTS

Sediment Depth (cm)	As in particulate form (mg As/kg dry wt)	As+5 in Interstitial Water mg/l	As+3 in Interstitial Water mg/l
0-2	150		
2-4	75		
4-6	75		
6-8	75	2.3	.39
8-10	75		
10-12	150		
12-14	220		
14-16	300	0.003	7.3
16-18	380		
18-20	450		
20-22	520		
22-24	600		
24-26	1800	0.59	3.7
26-28	2200		
28-30	4000		
30-32	4300		
32-34	3300		
34-36	2600	0.46	2.2
31-40			
40-51		0.11	0.45

3.3.2 Aquatic Fauna. Throughout the fauna section of this report Kam Lake will be compared to Grace, with the latter considered as a control. Kam and Grace Lakes are quite different in size, shape and depth and Grace Lake cannot be considered pristine due to arsenic apparently added from airborne sources. On the other hand, Grace Lake is ideal for comparative purposes because probably it represents the best in terms of water quality that could be expected from Kam Lake. Since Grace Lake is deeper and probably less productive than Kam, the present fish production in Grace Lake would likely be exceeded by Kam Lake when man made conditions no longer hinder productivity. Finally Grace and Kam Lakes are intimately connected by approximately 50 m (160 ft) of stream flowing from Grace Lake into Kam Lake. Any fauna in Grace Lake would likely be found in Kam Lake and vice versa, if conditions eventually allow. For these reasons, Grace Lake is considered a good comparison to Kam Lake for the purposes of this report.

The present discussion of the populations of fish and invertebrates is based largely on reports by Healey and Woodall (1973) and Falk et al (1973a and 1973b). These three reports are recent and contain the data that are used to describe the present situtation.

3.3.2.1 Zooplankton. A comparison of the available zooplankton data from Kam and Grace Lakes (Table 8) will show two factors: one, that there are about twice as many species in Grace Lake as in Kam Lake and secondly, that there are many more individuals in Kam than in Grace Lake. Almost all the zooplankton in Kam Lake are in two taxa, namely *Daphnia* and rotifers. Both the low species diversity and large populations of individual species are indicative of a somewhat polluted system. Further the presence of a large *Daphnia pulex* population is indicative of moderate organic pollution.

3.3.2.2 Macrobenthos. The data presented here (Table 9) indicates paucity of the deep benthos in Kam Lake. The sampled shallow benthic community in Kam Lake indicates a moderate paucity in both diversity and biomass. The lack of deep benthos in Kam Lake is likely due to the chronic arsenic pollution. The differences in shallow benthos between Kam and Grace Lakes are probably attributable to both chronic arsenic pollution and the addition of organic matter in Kam Lake.

TABLE 8

ZOOPLANKTON POPULATIONS FROM KAM AND GRACE LAKES
(DATA FROM HEALEY AND WOODALL 1973)

	Kam Lake		Grace Lake	
	Presence	No./10 l	Presence	No./10 l
Cladocera				
Daphnia pulex	Yes	540	No	0
Bosimina longirostris	No	0	Yes	0.4
Holopedium gilberum	No	0	Yes	0.8
Diaphanosma leuchtenbergianum	No	0	Yes	30
Leptodora kindtii	No	0	Yes	1.2
Copepoda				
Epischuia lacustris	Yes	Very Rare	Yes	4.8
Diaptomus sicilis	No	0	Yes	6.8
Cyclops bicuspidatus	No	0	Yes	
Cyclops vernalis	Yes	3,796	Yes	540
Cyclops scutifer	Yes		Yes	
Nauplii		1,716		136
Rotifers		71,196		6,628
Totals per 10 l.		77,248		7,348.0
No. of Crustacea Species		4		9

Another phenomenon that differentiates Kam and Grace Lakes is the June-August variation in zoobenthos. Grace Lake has a benthic growth that is typical of a relatively unpolluted system, that is, an increase in both numbers and biomass, during the growth season. Kam Lake, on the other hand, has virtually no increase in numbers and a decrease in biomass in this period. Such a situation is often indicative of relatively low production of these organisms and chronic pollution.

Another commonly accepted indicator of a distressed environment is that of diversity. If Kam and Grace Lakes are examined for the number of genera reported in the dipteran family Chironmidae, it is found that in Grace Lake there were eleven genera reported while in Kam Lake only five genera were reported. The lower diversity reported for Kam Lake suggests the possibility of some environmental impact from the current Kam Lake inflow.

3.3.2.3 Fish. At present five species of fish are know to inhabit Kam Lake, namely whitefish, cisco, pike, walleye and arctic grayling. In comparison, Grace Lake does not have the grayling but does have ling and stickleback in addition to the species found in Kam Lake. (Table 10).

The fish in Kam Lake, by comparison with Grace tend to have a lower average length, lower weight, lower median age, a shorter life and a lower population density. The cisco does not follow this trend except for population density.

The growth rate of whitefish in Kam exceeds that of Grace and the fish appear healthy. This can be said for all species with the possible exception of pike. Whitefish and cisco appear to have reproducing self sustaining populations in Kam Lake. No small pike have been taken despite catch attempts and it is suspected that there is no recruitment at present to the Kam Lake population (Falk et al, 1973). Grayling may enter Kam Lake in the spring from Great Slave Lake, while Grace Lake appears to have a self perpetuating population of all its species of fish.

The existing data suggests that Kam Lake at present is suffering from a low to moderate level of chronic pollution. However, it is possible that the situation could improve if future discharge of pollutants to Kam Lake was prevented.

3.3.3 Existing Biota Contamination.

3.3.3.1. Invertebrate Contamination. The snails from the benthos of Kam Lake were analysed for heavy metal uptake (Falk et al 1973) and high concentrations

TABLE 9

SUMMARY OF THE DATA ON ZOOBENTHOS FROM
KAM AND GRACE LAKES
(DATA FROM HEALEY AND WOODALL 1973 & FALK et al 1973)

	KAM LAKE			GRACE LAKE		
	Shallow	Deep	Ratio of Density:	Shallow	Deep	Ratio of Density
Abundance	No./m^2	No./m^2	June:Aug.	No./m^2	No./m^2	June:Aug.
Annelida						
Oligochaeta	1	0	NA	340	0	1 : 31
Mollusca						
Lymnaeidae	16	0	1 : 2.8	0	0	NA
Valvatidae	60	0	2 : 1	80	0	1 : 1.4
Sphaeridae	8	4	1 : 2.8	1852	0	1 : 2.4
Nematomorpha	0	0	NA	8	C	All August
Crustacea						
Amphipoda						
Pontoporeia	4	0	NA	1632	0	1 :22.6
Insecta						
Diptera						
Chironomidae	120	8	1 : 1	960	88	1 : 3.6
Ceratopagonidae	0	0	NA	28	0	All August
Trichoptera	0	0	NA	12	0	All August
Hemiptera	36	0	All August	0	0	NA
Ephemeroptera	0	0	NA	4	0	NA
Hydracarina	32	8	1 : 1.4	0	0	NA
TOTAL (No./m^2)	276	20		4916	88	

	JUNE	AUG	RATIO J : A	JUNE	AUG	RATIO J : A
BIOMASS (g. dry wt./m^2)	0.68	0.13	5.2: 1	0.68	3.10	1 : 4.6
RATIO OF NUMBERS			1 : 1.3			1 : 4.3

TABLE 10

A COMPARISON OF SOME OF THE PARAMETER OF THE FISH POPULATION IN KAM & GRACE LAKES

DATA FROM HEALEY AND WOODALL (1973)

Species	Average Length (cm)		Average Weight (grams)		Median Age		Age Range		Relative Population By Number*		Relative Population By Weight*	
	Kam	Grace	Kam	Grace	Kam	Grace	Kam	Grace	Kam	Grace	Kam	Grace
Coregonus clupeaformis Whitefish	33	43	831	1294	3	9	1-11	4-15**	21.1	100	13.6	100
Coregonus artedii Cisco	32	22	677	169	10	3	7-11	2-6	3.9	67.4	2.0	8.8
Esox lucius Pike	34	55	300	1348	4	8	3-5	7-10	5.9	9.8	1.4	10.2
Thymallus arcticus Grayling	32	-	533	-	3	-	2-3	-	8.9	0	3.7	0
Lota lota Ling	-	53	-	1063	-	-	-	-	0	5.0	0	4.1
Stizostedion vitreum Walleye	-	53	-	1861	-	-	-	-	0	2.1	0	3.0
Pungituis pungituis Stickleback	-	-	-	-	-	-	-	-	0	Found in fish stomach only	0	0

* Relative numbers and weights based on an arbitrary number of weight of 100 for Grace Lake Whitefish.

** Age range probably excludes the young fish due to gill net selectivity, however, in the case of pike, attempts were made to capture young without success.

of arsenic and copper were found. These concentrations would indicate some uptake from the substrate that could be passed up the food chain to fish. However, bio-accumulation of these heavy metals does not appear to be occurring at the fish level, as discussed below.

3.3.3.2 Fish Contamination. The Fisheries and Marine Service (Falk et al, 1973a and 1973b) and more recently the Environmental Protection Service (Wallace, 1974) analysed muscle, lever and kidney tissue of both Grace and Kam Lakes fish for heavy metal contamination. The toxicity of heavy metals varies with each metal and limits for human comsuption have been set by the Department of National Health and Welfare for Canada. These limits and the amounts of the various metals reported are illustrated in Table 11 and Figure 3. It is noteworthy that the heavy metals in fish muscle from Kam Lake never exceed national standards. Some muscle samples from Grace Lake pike exceeded the acceptable mercury limit and caution is urged here. If the liver is examined, one finds that pike from Kam Lake occasionally exceed the 1.2 ppm proposed level for lead. Liver contamination of both lead and zinc in walleye from Grace Lake exceeded the edible levels. It must be remembered that the liver of these fish are rarely eaten.

In summary, the concentrations of heavy metals in muscle tissue of Kam Lake fish at present is below the allowable limits for human consumption. However, since many heavy metals tend to accumulate in the consumer, recreational fishing use of Kam Lake will require continued monitoring of metal levels. In fact, data from Grace Lake would indicate that all lakes in the vicinity of Yellowknife including Yellowknife Bay, Great Slave Lake, should be consistently monitored.

Kam Lake has the potential as a valuable recreational fishery, as well as real value as an aesthetically pleasing waterbody, but the discharge of sewage to the lake would necessarily discourage recreational fishing because of public health considerations and degradation of the water quality will eventually destroy the aesthetic value of Kam Lake.

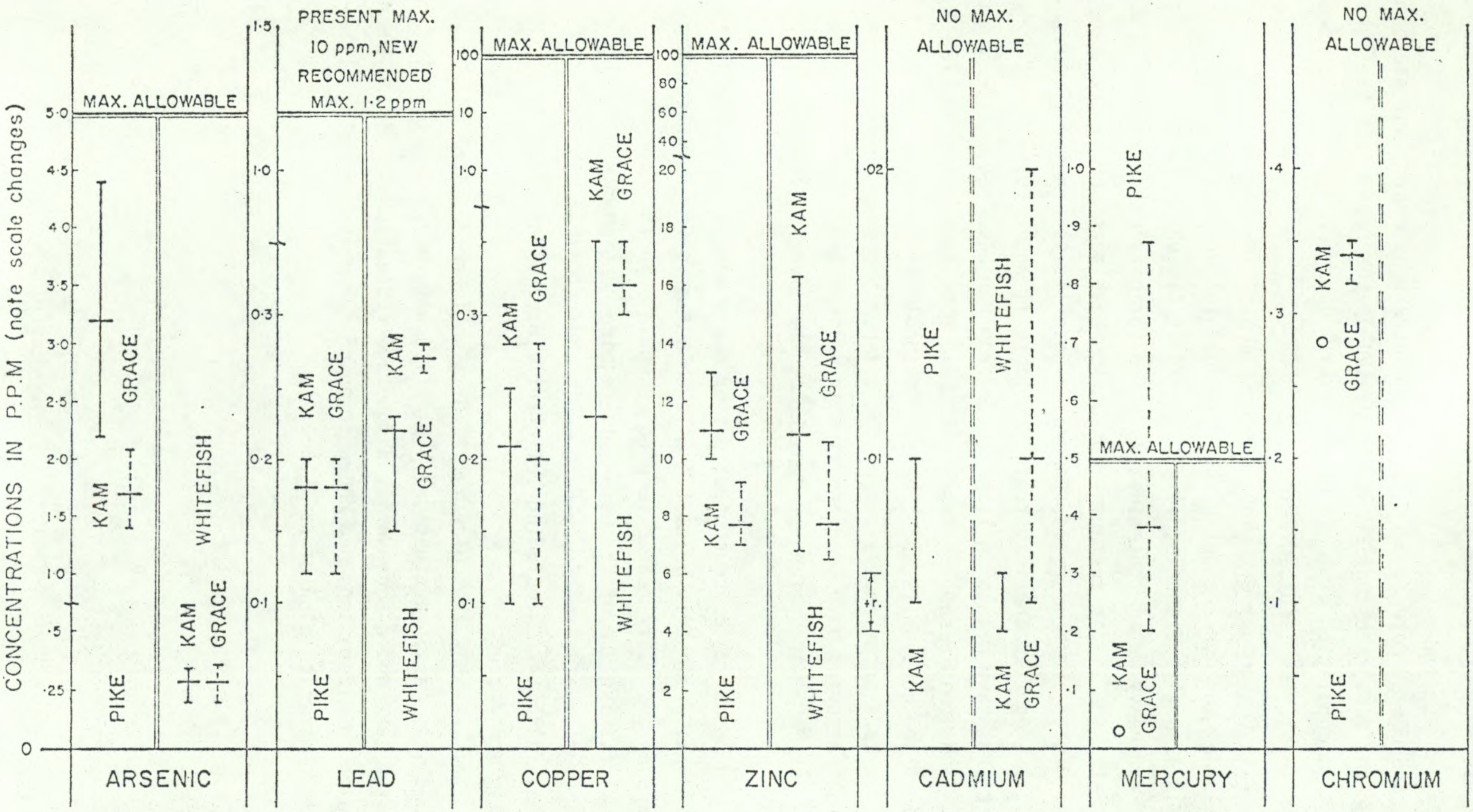


FIGURE 3

HEAVY METAL CONTAMINATION OF FISH MUSCLE FROM KAM AND GRACE LAKES

TABLE 11

A COMPARISON OF HEAVY METAL CONTAMINATION OF FISH FROM KAM AND GRACE LAKES

DARK OUTLINES EXCEED NATIONAL STANDARDS

Fish Species	Metal & Maximum Allowable Concentration in ppm	Range and Mean of Observed Concentration in ppm: Muscle, Kam	Muscle, Grace	Liver, Kam	Liver, Grace
Pike *Esox lucius*	Arsenic (5 ppm)	$\bar{x}$ 3.22 2.2 to 4.4	$\bar{x}$ 1.69 1.41 to 2.11	$\bar{x}$ 2.23 1.7 to 3.3	$\bar{x}$ 0.95 0.73 to 1.13
	Lead (1.2 ppm proposed 10 ppm presently)	$\bar{x}$ 0.18 0.14 to 0.20	$\bar{x}$ 0.17 0.14 to 0.20	$\bar{x}$ 1.41 1.1 to 1.8	$\bar{x}$ 0.13 0.10 to 0.21
	Copper (100 ppm)	$\bar{x}$ 0.21 0.10 to 0.25	$\bar{x}$ 0.20 0.10 to 0.28	$\bar{x}$ 27.1 15.6 to 37.2	$\bar{x}$ 3.8 3.10 to 4.4
	Zinc (100 ppm)	$\bar{x}$ 11.0 10.0 to 13.0	$\bar{x}$ 7.7 7.0 to 9.2	$\bar{x}$ 41.0 19.0 to 61.0	$\bar{x}$ 61.6 46.8 to 93.6
	Cadmium (No level set)	$\bar{x}$ 0.01 tr to 0.01	$\bar{x}$ - -	$\bar{x}$ 0.11 tr to 0.29	$\bar{x}$ - 0.01
	Mercury (0.5 ppm)	$\bar{x}$ - 0.03	$\bar{x}$ 0.38 0.02 to 0.87	$\bar{x}$ - -	$\bar{x}$ 0.22 0.10 to 0.42
	Chromium (No level set)	$\bar{x}$ - 0.28	$\bar{x}$ 0.34 0.32 to 0.35	$\bar{x}$ - -	$\bar{x}$ 0.29 0.24 to 0.43
	Nickel (No level set)	$\bar{x}$ - 0.28	$\bar{x}$ - -	$\bar{x}$ - -	$\bar{x}$ - 0.08
Whitefish *Coregonus clupeaformis*	Arsenic (5 ppm)	$\bar{x}$ 0.28 0.20 to 0.34	$\bar{x}$ 0.28 0.20 to 0.36	$\bar{x}$ 0.80 0.30 to 1.15	$\bar{x}$ 0.53 0.34 to 0.92
	Lead (1.2 ppm Proposed)	$\bar{x}$ 0.22 0.15 to 0.23	$\bar{x}$ 0.27 0.26 to 0.28	$\bar{x}$ 0.67 0.30 to 0.97	$\bar{x}$ 0.78 0.62 to 0.96
	Copper (100 ppm)	$\bar{x}$ 0.23 tr to 0.35	$\bar{x}$ 0.32 0.30 to 0.35	$\bar{x}$ 14.5 0.58 to 26.4	$\bar{x}$ 10.2 1.50 to 18.7
	Zinc (100 ppm)	$\bar{x}$ 10.9 6.5 to 16.3	$\bar{x}$ 7.7 6.5 to 10.6	$\bar{x}$ 52.4 45.7 to 58.11	$\bar{x}$ 49.5 40.0 to 61.8
	Cadmium (no level set)	$\bar{x}$ tr All tr	$\bar{x}$ 0.01 tr to 0.02	$\bar{x}$ 0.05 0.03 to 0.08	$\bar{x}$ 0.07 0.02 to 0.15
	Nickel (no level set)	$\bar{x}$ <0.1 <0.1	$\bar{x}$ 0.73 0.72 to 0.74	$\bar{x}$ - -	$\bar{x}$ 6.8 6.4 to 7.2
Walleye *Stizostedion vitreum*	Arsenic (5 ppm)	- <0.3	$\bar{x}$ 0.29 0.20 to 0.48	- <0.3	$\bar{x}$ 1.62 0.95 to 2.5
	Lead (1.2 ppm proposed)	$\bar{x}$ <0.5	$\bar{x}$ 0.22 0.15 to 0.33	<.05 -	$\bar{x}$ 3.2 0.98 to 8.7
	Copper (100 ppm)	- 1.19	$\bar{x}$ 0.23 tr to 0.35	- 56	$\bar{x}$ 28.5 18.6 to 38.0
	Zinc (100 ppm)	- 6.09	$\bar{x}$ 7.1 6.6 to 7.8	- 42.2	$\bar{x}$ 106.1 59.5 to 176.0
	Cadmium (no level set)	$\bar{x}$ <.01	$\bar{x}$ 0.01 tr to 0.02	- <.01	$\bar{x}$ 0.17 0.04 to 0.28
	Nickel	$\bar{x}$ <0.1	$\bar{x}$ 0.74	- <0.13	$\bar{x}$ 13.7

4 EFFECTS OF SEWAGE DISCHARGE ON KAM LAKE

4.1 Eutrophication and Associated Effects.

Based on limnological experience in Temperate climatic zones of Europe and North America, generalized relationships have been established between the rates of supply of nutrients and lake response (Vollenweider, 1968). The empirical data indicate that if nutrient supply (per unit lake volume or area) exceeds a given limit, the lake will grow more organic matter than it can decompose efficiently. Excessive nutrient supply usually results in oxygen depletion in deeper waters in mid summer and winter, nuisance blooms of algae, resulting in fish kills, offensive odors and health problems (Vallentyne, 1974).

Based on the waste load data from Table 3 the 1973 total nutrient loads from Yellowknife sewage would amount to approximately 4,000 kg (8,800 lb) of phosphorus and 11,000 kg (26,000 lb) of nitrogen per year. If this nutrient mass were added to Kam Lake, it would supply 1.9 g phosphorus per square metre of lake surface area per year and 5.2 g nitrogen per square metre per year. This rate of nutrient addition is greatly in excess of suggested "safe" limits for a lake of mean depth 5.5 m in temperate climate regions. It seems likely that subarctic and arctic lakes would have less capacity to absorb excess (man-produced) nutrient additions than temperate zone lakes. If the population of Yellowknife increased to 16,300 by 1990, Kam Lake would be grossly inadequate to metabolize the added nutrients. In this discussion it is important to realize that primary and secondary sewage treatment will do little to reduce the nutrient concentrations in sewage discharge to a lake.

The chemical composition of raw sewage presently being added to Kam Lake is given in Table 2 and the expected high concentrations of nutrients are evident. The concentration of particulate and dissolved organic carbon can be used to compute the minimal effect of sewage addition on the dissolved oxygen content of Kam Lake waters. The concentration of organic carbon in sewage multiplied by the present Yellowknife sewage discharge yields a mass of 54,000 kg of organic carbon per year. To this mass must be added the organic carbon fixed in excessive plankton growth which will be stimulated by the phosphorus and nitrogen in sewage discharges (Table 2). This source is estimated to be 400,000 kg of organic carbon per year based on empirical relations (Brunskill, 1974). Thus, roughly 454,000 kg of organic carbon will be added to the lake in a year, which will exert an ultimate demand for 1,200,000 kg of oxygen (O'Connor, 1968).

At any one time there is a maximum of 160,000 kg of oxygen dissolved in Kam Lake waters. During the open water season, there will be oxygen transfer from the atmosphere, and oxygen production from photosynthetic plants to assist in the oxidation of the sewage and satisfy the respiration demand of the excess plankton growth.

However, during winter, there is little plant photosynthesis and no transfer of oxygen from the atmosphere. During the 6-7 months of ice and snow cover on Kam Lake, the critical oxygen depletion situation would occur. This situation is depicted in Table 12, which clearly shows that during this period there will be insufficient dissolved oxygen available in Kam Lake to prevent the onset of anaerobic conditions.

Data from Alaska (Gordon, 1970) indicate that oxygen depletion at 0-5°C (32-41°F) occurs at a rate of 0.20 to 0.26 mg/l-hr. Since the saturation dissolved oxygen concentration at 0°C is only 14.6 mg/l it would suggest that if the sewage was well distributed throughout the lake, oxygen depletion in Kam Lake under winter ice would be rather rapid (i.e., less than one month). After the lake was depleted of all oxygen by winter sewage addition, anaerobic conditions would develop.

Although anaerobic micro-organisms are relatively efficient at degradation of concentrated organic wastes, they require relatively high temperatures to maintain efficient metabolism. As a result of the low ambient temperatures experienced in winter and the dilution of organic matter in Kam Lake only slow decomposition of organic wastes can be expected after the onset of anaerobic conditions. Nonetheless the presence of dissolved H_2S would be expected.

As well, when the sediment-water interface becomes oxygen deficient, at an oxidation reduction potential (E_h) of +200 mV to +50 mV, nutrients will be solubilized from the sediments and the lake will be subjected to an additional source of nutrients.

As a result of these conditions, a time period of little or no dissolved oxygen in the lake would occur and all fish, invertebrates and most photosynthetic plants would die very quickly.

4.2 Interactions of Sewage with Arsenic.

It is apparent that even with the introduction of the present Yellowknife sewage to Kam Lake, oxygen depletion will occur, particulary under winter ice and probably during thermal stratification.

TABLE 12

OXYGEN DEMAND ON KAM LAKE DURING WINTER ICE COVER

	Sources of Oxygen Demand	Ultimate Oxygen Demand*	Available Oxygen Resources
Sewage discharge 6-7 Mos (1975)			
TotalOrganic Carbon	31,000 kg	84,000 kg	
Total Nitrogen	6,400 kg	29,000 kg	160,000 kg (based on dissolved oxygen saturation at 1°C before freeze up)
Excess Plankton Biomass			
Total Organic Carbon	400,000 kg	1,100,000 kg	
Total Nitrogen	60,000 kg	270,000 kg	

TOTAL ULTIMATE OXYGEN DEMAND: 1,500,000 kg TOTAL AVAILABLE OXYGEN = 160,000 kg

* Based on organic carbon oxygen demand = 2.7 x (organic carbon mass)
nitrogenous oxygen demand = 4.6 x (nitrogen mass)

Bacteria require oxygen for respiration and once the oxygen level is at zero they look for alternate electron acceptors. As the oxidation reduction potential drops they use nitrate (NO_3) and then sulphate (SO_4) and finally carbon dioxide (CO_2). This produces nitrogen (N_2), hydrogen sulphide (H_2S) and methane (CH_4).

Bacteria will also oxidize and reduce various forms of arsenic. The greater abundance of bacteria and organic matter in the lake as the result of sewage discharges may play a key role by producing reducing (anaerobic) conditions, thereby, producing the more toxic As^{+3} form (Ferguson and Gavic 1972; McBride and Wolfe, 1971; Wolfe 1971). Similarly, under aerobic conditions arsenic sulphide (As_2S_3) could be oxidized to arsenite (As^{+3}) and arsenite could be oxidized to arsenate(As^{+5}). Several other microbial interactions with arsenic are summarized in Table 13.

Reduced arsenic, as inorganic arsenite, is probably sufficiently toxic to obliterate the planktonic (including fish) and benthic forms of life in the lake. Other more severely toxic forms of arsenic (methyl arsine, dimethyl arsine, trimethyl arsine, methyl arsonic acid, cacodylic acid, and trimethyl arsenic acid) are also likely to be formed by anaerobic microorganisms (Wolfe, 1971). It appears possible that one or several of these potential toxins would inhibit normal microbial degradation of the sewage, and also inhibit the growth of photosynthetic algae and bacteria that supply oxygen to the water during the open water season.

In order to determine the current presence of organic arsenic compounds in Kam Lake sediments, the Environmental Protection Service in conjunction with the Fisheries & Marine Service collected several sediment cores from three stations in Kam Lake. These were analysed for dimethylarsine by Dr. J. VanLoon (U of Toronto) and were found to contain no detectable quantity of that compound.

At the Freshwater Institute hydrogen sulphide (H_2S) a common sewage degradation product has been bubbled through Kam Lake waters and has quantitatively reduced <u>all</u> of the As^{+5} to the more toxic As^{+3} form. Furthermore, continued bubbling of this solution with air (containing oxygen) failed to oxidize this As^{+3} over a period of two months. From this crude experiment it is concluded that As^{+5} reduction to As^{+3} will be relatively rapid in Kam Lake, but that aeration will not result in rapid detoxification or oxidation of reduced arsenic species. In addition, this phenomenon will likely impede sewage degradation in the lake. Reduced arsenic (as arsenite, As^{+3} or as various

TABLE 13

MICROBIAL INTERACTIONS WITH INORGANIC ARSENIC

F. ferrooxidans	As_2S_3 oxidized to AsO_3^{-3} AsO_4^{-3}
Heterotrophic Bacteria	AsO_3^{-3} oxidized to AsO_4^{-3}
Achromobacter	" " "
Pseudomonas	" " "
Xanthomonas	" " "
M. lactilyticus	AsO_4^{-3} reduced to AsO_3^{-3}

ARSENIC CONTAINING MINERALS OXIDIZED BY THIOBACILLI

Arsenopyrite	$FeS_2 . FeAs_2$
Enargite	$3Cu_2S. As_2S5$
Orpiment	As_2S_3

methylated forms of arsenic) throughout the year and severe oxygen depletion under winter ice will likely kill all fish, macro-invertebrates, and most photosynthetic plants in the lake very soon after the addition of sewage to the lake in winter.

4.3 Public Health Considerations.

Domestic sewage contains large numbers of bacteria most of which are normal inhabitants of the human intestine. In addition, large numbers of organisms pathogenic to man are also present. Many diseases are potentially water-borne (including transmission by fish) and can therefore be transmitted as a result of sewage contamination of water. These include cholera, dysentery (amoebic and bacillary), infectious hepatitis, typhoid, leptospirosis, salmonellosis, tularemia, Diphyllobothrium latum (Smith et al, 1964), poliomyeltis and enterovirus infections. In general, the spread of these diseases is controlled by adequate treatment and disinfection of sewage and potable water supplies, although some of the infective agents are resistant to disinfection. Even with such precautions, outbreaks still occur. Cholera has been reported in Italy (1973) and typhoid in the U.S. and Canada (1973) and numerous outbreaks of salmonellosis have occurred in recent years.

Sufficient epidemiological studies have not been undertaken for the establishment of truly meaningful standards applicable to swimming waters, nevertheless, almost all provinces have adopted standards for the sewage indicator organisms: coliforms, fecal coliform and fecal streptococci. For aesthetic and recreational purposes these standards are generally: coliform 1,000 per 100 ml; fecal coliform 100-200 per 100 ml and fecal streptococci 20-100 per 100 ml. These generally accepted standards are used to indicate the presence of sewage contamination which implies the possible presence of enteric pathogens (including viruses). If the indicator limits are exceeded then a potential health hazard exists.

There can be no question 3,200,000 l/day (700,000 imp gal/day) of sewage will quickly bring the average counts in Kam Lake beyond those limits. Normal coliform counts in the sewage will be in the order of 10^7 to 10^8 per 100 ml and fecal coliforms about one order of magnitude lower. It has been shown that fecal coliforms and some pathogens such as Salmonella have similar survival rates and they can survive for many months (Geldreich, 1973) in lakes and rivers. It will only be a matter of time until this lake becomes highly polluted and a potential threat to public health. People using the lake could become infected by ingestion or body contact and through handling or eating the fish found therein. Fish are now thought to be an important vector of human disease and are a well noted vector in Japan for the spread of cholera. They are also a source of Aeromonas, Pseudomonas and other Vibrio species which can cause disease in man.

The bacterial levels in the lake would quickly reach levels where the water would not be suitable to supply a disinfected potable water system. Recommended coliform levels for such a supply are usually 5,000 per 100 ml.

In addition to the spread of enteric infections, there would be an increased probability for those coming in contact with the lake water to contact upper respiratory tract infections. There have been increasing reports of swimmers infections of the eye, ear, nose and throat. Organisms such as Pseudomonas aeruginosa, Staphylococcus aureus and Group A beta haemolytic streptococci are organisms involved in these infections and they can all be isolated in sewage.

In summary, the discharge of sewage to Kam Lake would undoubtedly create a significant potential hazard to public health by establishing a micro-biologically contaminated water body in close proximity to major residential areas.

4.4 Future Kam Lake Biological Communities.

While speculating on the future of the macro-fauna of any body of water is dangerous, some educated guesses can be made in the case of Kam Lake. Three situations will be examined:

a. Carrying out present plans with the addition of about 3,200,000 l/day (700,00 imp gal/day) sewage.
b. Keeping the status quo, i.e., about 120,000 l/day (27,000 imp gal/day) sewage entering Kam Lake.
c. No further sewage entering Kam Lake.

4.4.1 Completion of Present Plans. If the sewage from the City of Yellowknife enters Kam Lake without treatment for essentially 99% phosphorus nitrogen removal and BOD removal then undesirable results will ultimately occur. They will likely include a shift of the plankton and benthic fauna to those that can resist high levels of pollution and ultimately a die off of all aerobic macro-fauna when the dissolved oxygen reaches zero. Complete dissolved oxygen depletion is most likely to occur under winter ice, but it would be expected that some oxygen levels would be restored in summer and the repopulation of some sewage tolerant organisms should occur. Ultimately it is anticipated that summertime oxygen depletion would also occur.

It is predicted that fish populations would be eliminated. Further, if sewage discharge to Kam Lake were to occur it is likely that even if subsequently stopped at some time in the future, the return of the lake to useable conditions would be very protracted. Little data exists on Arctic ecosystems but recovery would likely take longer than would be the case for temperate ecosystems. Such temperate systems have been known to show great improvement in from about three to twelve years after sewage addition is stopped, depending on the rate of flushing. Kam Lake is estimated to take four years for a complete water exchange. Thus, progressing at temperate climate rates a couple of decades would be required for self-cleanup, but at subarctic rates probably a longer time would be required. In other words, if sewage is added for only one year the lake would probably not fully recover until around the year 2000.

4.4.2 Status Quo. Little attention will be paid to this situation as it is not likely to occur and would probably be very difficult to maintain. However, if the status quo were maintained, the eutrophication of Kam Lake would increase and in the foreseeable future one would predict occassional kills of various species of fish. The situation that presently exists will probably continue with a slow decrease in the heavy metal pollution and a probable increase in the contamination by microbial pathogens. Thus, the lake would become of decreasing value to the commuity.

4.4.3 Elimination of Sewage Discharge to Kam Lake. Under this condition it is predicted that Kam Lake could reach its full potential as a recreational fishery and community amenity. At the same time it should be cautioned that instant improvement cannot be expected. The following sequence of events is predicted:

Plankton - A gradual increase in the species diversity with a decrease in the present major groups, i.e., *Daphnia* and rotifers.

Benthos - An increase in diversity and population densities especially in the shallow benthic community. There would probably be an increase in deep benthos but this would take much longer as this community may well be affected by the persistent arsenic in the sediments.

Fish - The changes will be slow and may not at first appear favourable. Pike may establish a reproducing population and also increase their growth rate as more small fish establish in the lake. Whitefish may well initially decrease their growth rate due to the expected reduction of the *Daphnia* population.

However, in the long run an increased population of larger fish is expected. They will probably shift their diet from plankton toward a mixture of plankton and benthos.

Generally speaking the following is likely to occur:

a. There will be increases in population, average size, average age and fish biomass and a decrease in growth rates.

b. There will be an increase in total fish productivity to a level exceeding that of Grace Lake.

c. There will be decrease in heavy metal contamination with time.

d. Kam Lake will establish a viable recreational fishery.

e. Kam Lake will be preserved as an aesthetically valuable waterbody in close proximity to the new residential area of Yellowknife.

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