kiggavik Uranium Project

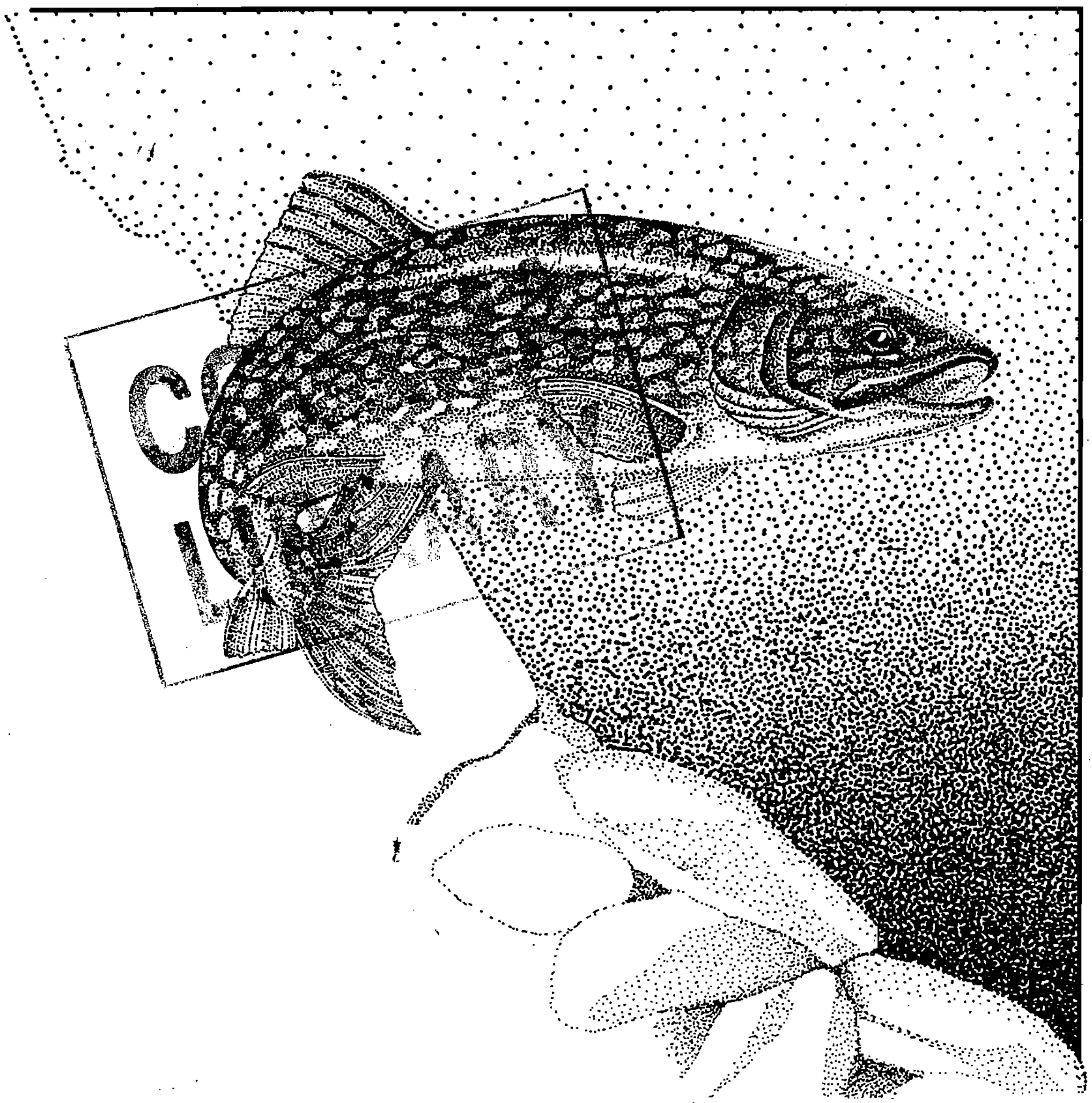
Baker Lake Northwest Territories Canada

Environmental Assessment

Prepared by Beak Consultants Limited

Supporting Document No. 4

The Aquatic Environment



Urangesellschaft Canada Limited

Toronto, Ontario Canada
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SUPPORTING DOCUMENT 4

AQUATIC BASELINE CONDITIONS - KIGGAVIK PROJECT AREA
District of Keewatin, Northwest Territories

A Report to:

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1.0 SUMMARY

The aquatic environment in the Kiggavik project area has been studied for almost a decade to determine baseline conditions; to identify areas and ecosystem components that may be affected by site activity; and to provide necessary information to facilitate the design of the project in a manner that is most compatible with the environment.

The Kiggavik project area is situated in the headwaters of the Aniguq River, a relatively small watershed situated between the Thelon River to the north and the Kazan River to the south. The Aniguq River drains into Baker Lake, and eventually on into Hudson Bay.

Hydrologic studies of the Kiggavik project area were carried out in 1988 and 1989 to measure local runoff characteristics, which are important in evaluating the downstream transport and dilution of site runoff and treated wastewater. These studies have shown that most of the annual runoff from the site occurs during the spring snowmelt in June and July, with little runoff during the rest of the year. Several relationships were developed to predict hydrologic responses in the study area to precipitation and snowmelt. Local hydrologic conditions are placed in a regional perspective through comparison with Environment Canada monitoring data on the Aniguq system, as well as with hydrologic information on Baker Lake and Hudson Bay. Other studies of the physical attributes of watersheds in the area included the determination of the bathymetries of lakes in the project area.

Water quality conditions were measured to define baseline concentrations of trace metals, radionuclides, nutrients and major ions in local watersheds. It was generally found that project area waters are relatively low in conductivity and contain relatively low concentrations of most dissolved substances. Low nutrient (phosphorus) concentrations suggest that local lakes are relatively unproductive. Background radionuclide levels are also relatively low, and only appear to be affected by the uranium mineralization in a small stream draining the ore body area.

The physical and chemical characteristics of lake sediments were measured because lake sediments act as sinks for metals and radionuclides. Sedimentation rates were measured to permit the estimation of future chemical fluxes from the water column. The lakes were found to have low but variable sedimentation rates reflecting the general unproductive conditions of the aquatic ecosystem.

Study area lakes support a wide variety of aquatic life. Studies of plankton and benthic communities were carried out to determine baseline conditions and to evaluate the effectiveness of monitoring these communities to measure environmental change. Plankton communities in the area were found to be extremely variable in terms of species composition and numbers of organisms, and probably offer little potential for operational monitoring except to identify gross changes. Benthic communities in Kiggavik area streams contain a variety of species and, as in other biomonitoring applications, can probably be used as a monitoring tool in the operational phases of the Kiggavik project.

Fish communities in Kiggavik project area lakes are dominated by lake trout and Arctic grayling, with round whitefish, cisco, burbot, ninespine stickleback and sculpin also present in some waterbodies. Lakes that freeze to the bottom and have only limited inlet and outlet streams are fishless. Deeper lakes, such as Ridge Lake and Cirque Lake, which have tributaries that offer no potential for fish passage, tend to have limited fish communities due to their isolation. Shallow lakes with larger inlet and outlet streams, such as Pointer Lake, have periodic winterkills but are readily repopulated from elsewhere in the watershed. Judge Sissons Lake, the largest lake studied, has a full complement of all species found in the area. No Arctic char occur in the upper Aniguq watershed.

The aquatic baseline conditions described in this report provide a foundation for the design of an aquatic environmental monitoring program for the Kiggavik project. Further, this information provides a basis for the prediction of the effects of project development on the aquatic environment and aquatic resources used by local populations living at Baker Lake and elsewhere in the region.

2.0 INTRODUCTION

Urangesellschaft Canada Limited has sponsored extensive research on the aquatic environment around the Kiggavik project site, including studies on water quality, hydrology, sediment quality and aquatic biota. This report describes the baseline characteristics of the aquatic environment.

In the mid-1970s, Urangesellschaft Canada Limited discovered a uranium deposit within the Kiggavik area. After extensive mineral exploration, an engineering feasibility study for the development of a uranium mine and mill at site was commissioned. An environmental impact assessment was also carried out to evaluate the effects of the project, and to provide environmental guidance in the development. Several years of baseline environmental studies on the aquatic environment were carried out in support of this assessment. This support document provides a review of these studies and of other information and data on regional aquatic resources from government and other resource sources.

Aquatic field studies were carried out in 1979, 1980, 1986, 1988 and 1989 to characterize environmental conditions and to provide baseline data for predicting effects from any future site development and to provide environmental guidance in the project design. The 1979 and 1980 surveys were broad and general in scope, since site development had not been conceptualized in detail. The 1986 studies, which are outlined in a report by BEAK (1988), were carried out as part of the engineering pre-feasibility study, and were more focussed on environmental conditions relevant to the initial conceptual project design. In 1988 and 1989, field surveys were carried out in conjunction with the engineering feasibility study to fill information gaps that became apparent as the more detailed project design unfolded. In addition, these most recent studies were carried out to address some of the concerns and comments expressed by the Regional Environmental Review Committee on the Project Concept Description document (BEAK, 1988). This report describes the results of all aquatic environmental studies carried out between 1979 and 1989 for the Kiggavik project.

In undertaking these studies, it should be pointed out that the type of study and the intensity of study varied from lake to lake and watercourse to watercourse. Pointer Lake was studied in more detail than other study area lakes, because it is the first large waterbody downstream of the mineralized area, and would almost certainly be affected by the development of a mine in the area. Other lakes and watersheds in the area were investigated to provide a broad picture of local aquatic conditions, and to provide some baseline information on areas that may be affected by facilities that may be developed with the mine. As the project evolved and became better defined, it became possible to better identify those areas where aquatic studies should be focussed. This document provides an account of all of the aquatic environmental studies carried out in support of exploration and development activities at the Kiggavik project site.

3.0 STUDY AREA

The Kiggavik site (64°25'N, 97°37'W) is located in the sub-Arctic tundra of the central Keewatin District in a region drained by Baker Lake, which flows into Chesterfield Inlet and Hudson Bay (Figure 3.1). Major water resources in the region include the Thelon River and two large lakes along its course - Schultz Lake to the north and Aberdeen Lake to the west. Judge Sisson's Lake is a relatively large regional lake that drains most of the Kiggavik project area. Sisson's Lake empties into the Aniguq River, which flows eastward into the western end of Baker Lake and follows a course that is roughly parallel to the Thelon River situated to the north. Numerous lakes and rivers dissect much of the region, and tundra wetlands are predominant throughout. Figure 3.2 presents the local perspective on the Kiggavik study area.

The Kiggavik site is situated at the eastern end of the Thelon Basin. The basin is filled with a thick deposit of clastics and small amounts of felsic volcanics. The pre-Thelon clastic rocks are mainly arkosic quartzites, with intercalated orthoquartzites and chlorite-sericite schist units. Except for the chemically inert orthoquartzites, all the metasediments are host to uranium mineralization. This bedrock influences the chemistry of the surface waters of the region seasonally through seepage from the shallow active zone, and on a more year-round basis through discharge of small quantities of deep groundwaters into the deeper waters of large lakes.

The surficial materials in the study area can be grouped into glacial deposits, including tills and glaciofluvial materials, fluvial deposits, resulting from recent activity, and organic deposits, resulting from gradual accumulation of peats. The site lies in a zone of continuous permafrost, with regional thicknesses greater than 200 m. The active layer reaches about 0.50 m to 1.25 m on well-drained tills, and about 0.80 m on wet peatlands. The soils are generally dominated by clay-rich till, although organic cryosols and fibric- to mesic-peats are present in wetter areas. A large proportion of the area is wetland, with the remainder being occupied by lakes and dry upland tundra. Cryogenic processes, especially cryoturbated soils, are evident and associated with patterned ground features.

The region is north of the treeline and surface cover is composed of a variety of lichens, mosses, ericaceous shrubs and heath species, and by a variety of herbs, grasses and sedges. Further information on soils and vegetation can be found in Supporting Document No. 2.

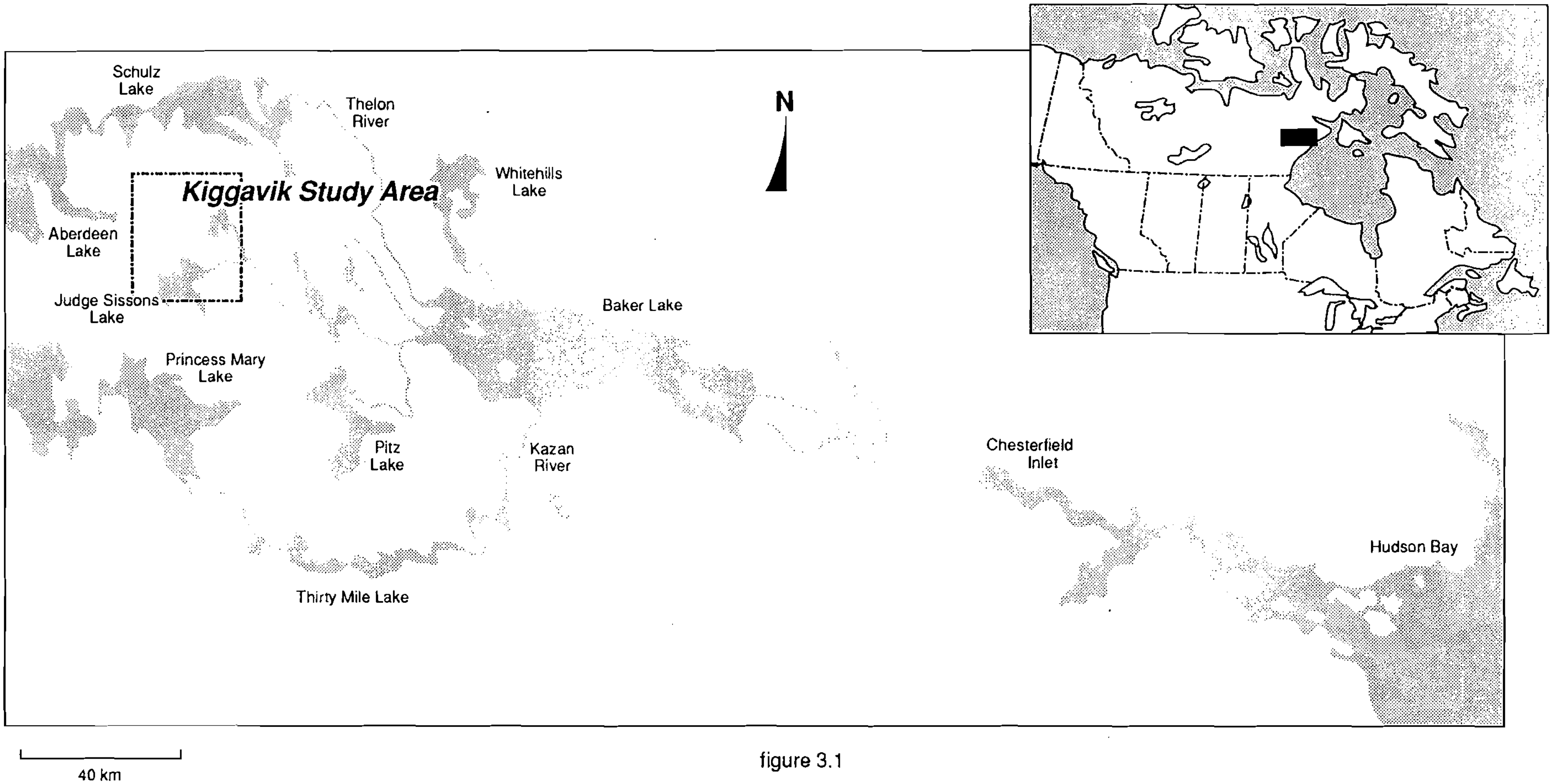


figure 3.1

Project Location Map ***District of Keewatin, Northwest Territories***

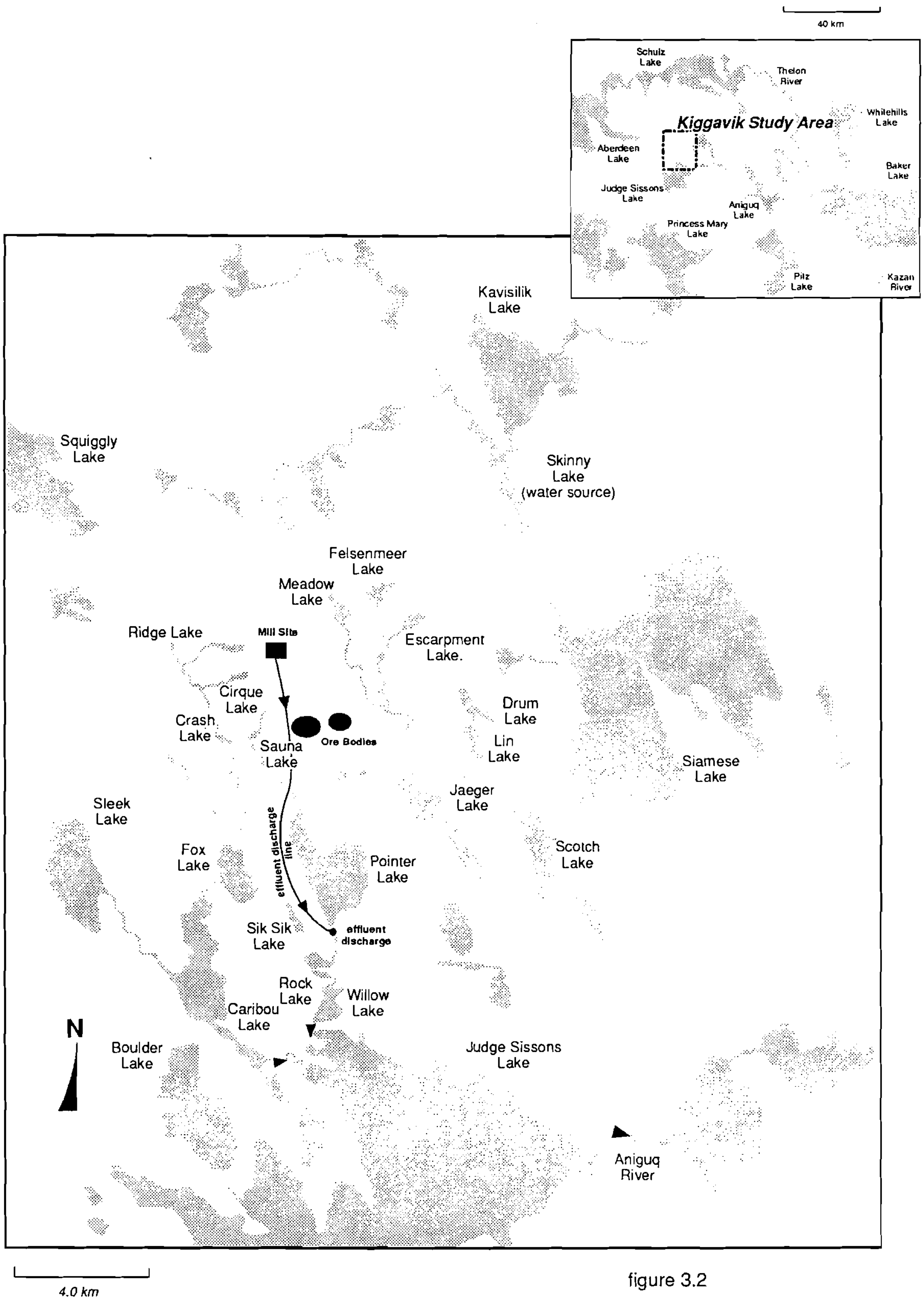


figure 3.2

Kiggavik Study Area

Based on data collected at Baker Lake (the nearest Atmospheric Environment Service monitoring station), the area receives approximately 235 mm as precipitation annually (30-year normal), of which about 60% occurs as rain. The snow-free period is limited to July and August. The daily mean air temperature rises above 0°C during the first two weeks of June, and then falls below 0°C during the last two weeks in September. The mean annual air temperature is -12°C. The Kiggavik area is thus characterized by long, cool winters, very short transitional seasons, and short warm summers. The climate is classified as cold continental, and the region is dominated by Arctic pressure systems. A more complete discussion of climate for the area can be found in Supporting Document No. 1.

The Kiggavik site lies at an elevation of about 180 m and is 75 km west of the Baker Lake meteorological station (elevation at 12 m). The highest ground between the Kiggavik and Baker Lake rises to 230 m, approximately 30 km due east of the site. There are likely to be some differences in the meteorological conditions between the two sites because of the higher elevation of the Kiggavik site, and the effect of Baker Lake during the ice-free season. The difference in elevation may cause temperatures to be slightly lower at Kiggavik because of probable slight increases in wind speeds. There may also be a slight increase in precipitation at Kiggavik because of low clouds and fogs.

Baker Lake itself will have a moderating effect at Baker Lake. The small shallow lakes near the project site would not be expected to have as marked an effect. Spring and summer temperatures would be kept lower at Baker Lake, while fall temperatures would likely be higher.

Runoff and streamflow characteristics in the region are governed by topography, soil and plant communities and meteorological conditions. The cold Arctic climate results in the development of a thick layer of ice on surface water for about eight months of the year. By the end of winter in May, ice thickness in the project area is generally about 2 m. Runoff during these periods is negligible, and streamflow is greatly diminished or ceases completely.

There are generally three major periods of hydrologic activity in the central Keewatin region:

- **Spring snowmelt** is the largest source of water to regional watersheds (Roulet, 1985). Peak runoff occurs when meltwater exceeds the storage capacity of upland and lowland (wetland) soils. Snowmelt generally causes rapid rises in discharge hydrographs, with peaks reached only a matter of days after the initiation of melt. This results because of the very low storage capacities of soils at this time.
- **Early and mid summer** is the period when most of the basin snow cover is depleted and evapotranspiration is active. The basin dries out gradually, leading to a decrease in the permafrost groundwater table. As the frost table deepens, there is greater storage capacity in the active layer and so streamflow is reduced. The exception during this period is the wetlands, which undergo slow thawing and usually receive lateral inflows to maintain saturated conditions.
- **Rainy periods of late summer** occur when evapotranspiration decreases due to an increase in cloudiness and a decrease in daylight hours. In low-lying areas,. the watertable may rise to the ground surface, so that moderate to heavy rainstorms can generate sporadic high flow events.

The ponds, lakes and streams of the Baker Lake region support communities of aquatic life that play important roles in the local and regional ecosystem, and provide food and employment for members of the local population through fishing. Baker Lake and the major tributary streams support fisheries for Arctic char and whitefish. Other important fish, particularly from a sportfish perspective, include lake trout and Arctic grayling. Fish of the Kiggavik area are not known to be exploited by residents of the region, because the most significant inland fisheries resources of the area occur elsewhere in larger regional lakes and rivers, such as Baker Lake, the Thelon River and associated large lakes to the north, and the Kazan River watershed to the south.

4.0 SURFACE AND GROUNDWATER HYDROLOGY

4.1 General Physical Characteristics of Watersheds

The morphometric characteristics of lakes are important in terms of defining habitat conditions for aquatic life, determining the potential yield (harvest) of fish available, and for determining hydraulic (flushing) characteristics that are required for predicting pathways for the dispersion and dilution of solute discharges released into aquatic environments (see Supporting Document No. 7). Accordingly, bathymetric surveys were carried out on several Kiggavik study area lakes in 1979, 1980 and 1986, including Pointer, Jaeger, Scotch, Ridge, Escarpment and Judge Sisson's Lakes. Bathymetric maps for these and other lakes are presented in Appendix 1, along with notes on other morphometric characteristics and the fish community present. Summary statistics on these morphometric characteristics are presented in Table 4.1.

Kiggavik study area lakes in the upland headwaters of Judge Sisson's Lake are typically small and deep. Intermediate elevation areas contain both relatively large and small lakes, with several of the larger lakes ranging between 100 and 400 ha in area. Many of these intermediate lakes tend to be relatively shallow, with mean depths of less than 2 m; this morphometry is consistent with the more limited relief of the tundra plain area to the south of the escarpment.

Judge Sisson's Lake is the largest of the Kiggavik study area lakes examined, covering an area of 9,550 ha, including the large island occupying the central basin. The lake is also relatively deep (mean depth of 4.6 m), with a maximum depth of 20 m. The capacity (volume) of Sisson's Lake, at 440 million cubic metres, is more than ten-fold greater than Squiggly Lake, the second largest lake studied. Squiggly Lake, so named because of its highly indented shoreline, is a large (638 ha), deep (mean depth 6 m) lake located to the northwest of the mineralized zones, and is the only lake studied that drains northward into the Thelon River system.

Downstream from Judge Sissons Lake, the Aniguq flows eastward into Audra Lake, also known as Long Lake, which is the largest lake between Judge Sissons Lake and Baker Lake along the watercourse. Bathymetric mapping has not been carried out for this lake; however, based on a low altitude helicopter overflight, the lake appears to have a depth similar to Judge Sissons, relatively shallow with about half of the lake bottom visible. For this study, it is reasonable to assume that the mean depth of Audra Lake is about 4 m.

Baker Lake itself is large, and covers an area of about 1,890 km^2. Detailed bathymetric mapping of the lake is unavailable, although hydrographic charts are available for the northern portion of the lake along the shipping route between Chesterfield Narrows and the village of Baker Lake. For impact assessment purposes, it is assumed that Baker Lake has a mean depth of 15 m.

Baker Lake empties into Hudson Bay through Chesterfield Inlet. Hudson Bay, exclusive of James Bay, covers a surface area of some 740,000 km^2, and has an average depth of about 120 m (Prinsenberg, 1980). The Bay discharges through Hudson Strait along the surface, as relatively low salinity water, while there is a smaller return of high salinity water at depth through the Strait.

Lake volumes and drainage areas (Table 4.1) are used in the derivation of hydrological characteristics in the following subsection.

4.2 Local Watershed Hydrology

4.2.1 Purpose and Objectives

The purpose of the following section is to provide an analysis of the surface water hydrology for predictive purposes. The objective is to carry out such an investigation. There are a number of aspects about the hydrology of the Kiggavik area that must be known and assessed. These involve:

- assessing the appropriateness of using Baker Lake meteorological data to estimate conditions and hydrologic inputs at the Kiggavik project site, some 75 km to the west;
- determining the magnitude and timing of the response of watersheds in the Kiggavik project area;
- evaluating the proportions of total available water lost by evapotranspiration and runoff;

TABLE 4.1: MORPHOMETRIC CHARACTERISTICS OF KIGGAVIK AREA AND REGIONAL WATERBODIES

Lake[1]	Surface Area (ha)	Lake Volume (m^3)	Mean Water Depth (m)	Drainage Area (km^2)
Ridge Lake	16.7	$3.8x10^5$	2.3	2.3
Cirque Lake	5.6	$1.5x10^5$	2.6	1.1
Crash Lake	8.1	$8.7x10^4$	1.1	14
Fox Lake	128	$2.2x10^6$	1.7	29
Caribou Lake	341	$4.9x10^6$	1.4	80
Caribou Lake System, at Inlet to Judge Sisson's Lake	-	-	-	86
Felsenmeer Lake	20.8	$4.2x10^5$	2.0	1.4
Escarpment Lake	13	$2.8x10^5$	2.2	2.4
Meadow Lake	14	$1.2x10^5$	0.8	4.1
Drum Lake	25	$3.3x10^5$	1.3	5.4
Lin Lake	48	$6.3x10^5$	1.3	7.6
Scotch Lake	201	$7.1x10^6$	3.5	19
Jaeger Lake	281	$4.6x10^6$	1.6	56
Pointer Lake	374	$5.6x10^6$	1.5	82
Sik Sik Lake	16	$1.3x10^5$	0.8	2.4

TABLE 4.1: MORPHOMETRIC CHARACTERISTICS OF KIGGAVIK AREA AND REGIONAL WATERBODIES

Lake[1]	Surface Area (ha)	Lake Volume (m^3)	Mean Water Depth (m)	Drainage Area (km^2)
Willow Lake	55	$7.7x10^5$	1.4	104
Judge Sisson's Lake	9,550	$4.4x10^8$	4.6	680
Skinny Lake	197	$6.1x10^6$	3.1	122
Kavisilik Lake	564	$2.4x10^7$	4.2	156
Siamese Lake	2,750	-	-	85
Squiggly Lake	638	$3.8x10^7$	6.0	56
Audra Lake	9,520	$3.8x10^8$	4**	-
Aniguq River, at Mouth (including Pitz Lake Drainage)	-	-	-	5,250
*Aniguq River Downstream of Audra Lake	-	-	-	3,200
Baker Lake	189,000	$2.8x10^{10}$	15**	230,000
Chesterfield Inlet	-	-	-	276,000
Hudson Bay	740,000	$8.9x10^{13}$	120	2,456,400 (land mass) 810,000 (water surface)

1 Local lake names are as defined on Figure 3.2.

* Environment Canada monitoring station.

** Assumed values.

- o determining whether Kiggavik area watersheds are interconnected, so that changes in one watershed affect all others;
- o estimating the total discharge from Kiggavik area watersheds; and
- o estimating the proportion of total water input to Baker Lake that is attributable to runoff from the Kiggavik project area.

All of the above determinations may be made, at least in part, with the data available for this analysis. Many assumptions have been made, which will be discussed in a later sub-section.

4.2.2 Methodology

The objectives of this report are fulfilled by a detailed analysis of the available data.

- o To determine whether the Baker Lake meteorological data can reasonably be used to estimate inputs to Kiggavik, daily mean air temperatures measured at Baker Lake in 1982 and 1983 are compared with those measured at Kiggavik over the same period by Roulet and Woo (1986).

- o The system response (i.e., response ratio) of Kiggavik area watersheds is calculated from six watersheds where runoff data are available (i.e., 1988 and 1989 data for Ridge, Pointer, Jaeger, Cirque, Skinny and Escarpment Lakes). The response ratio is defined by the ratio between net runoff and total available water. This equation is complicated because allowances have to be made for:

  - discharge measurements at lake outflows instead of inflows, and
  - rain events that occurred during spring and summer.

  Before hydrologic responses are calculated, the snowmelt period requires definition. There is no definitive means of determining this period, so for this report it is assumed to occur from the time of first hydrograph response (before peak flow) to the time the hydrograph recession "levelled off" (i.e., some time after peak flow).

The total available water (TAW) is then computed as the sum of:

- snow-water equivalents (on the basins and lakes),
- precipitation (only from after the time the snow transect data were collected), and
- active layer melt.

The net runoff attributed to snowmelt (NR) is computed by calculating the area under the hydrographs (for the snowmelt period) and then by subtracting all precipitation events occurring during this period.

o The proportional losses of total available water to evapotranspiration and runoff are determined by calculating a water balance for each watershed (i.e., by comparing total water inputs and outputs). Total inputs and total runoff are calculated as described above. The water lost by evapotranspiration (ET) is estimated using the Thornthwaite method. Although there are better methods of determining ET, none were developed for sub-Arctic environments. With the data available, Thornthwaite offered the best approach.

The Thornthwaite method assumes a certain amount of ET based on given air temperatures. Evapotranspiration refers to water losses from:

- free water bodies,
- transpiration, and
- base soils.

Evapotranspiration in a sub-Arctic environment, such as the Kiggavik site, occurs from lake surfaces and vascular plants. In contrast to those areas where the method was developed, not all of the Kiggavik area undergoes water loss by evaporation or transpiration. Much of the ground surface, for example, is exposed bedrock. For this reason, the ET values computed using the Thornthwaite method are adjusted to represent the actual amount of area that undergoes water loss. In the Kiggavik area, this involves computing the proportion of total area that is lake and vascular plant. The ET values computed using Thornthwaite are then adjusted by this fraction.

The Thornthwaite method requires that mean monthly air temperatures be available for the year of interest. The Thornthwaite equations are given below:

$$I = \sum_{i=1}^{12} \left[\frac{T_{ai}}{5}\right]^{1.514}$$

where: I = annual heat index, and

T_{ai} = mean monthly air temperature (°C) for each month of the year.

$$Et = 1.6\left[\frac{10(Ta)}{I}\right]^{a}$$

$$a = 0.49 + (1.79 \times 10^{-2})I - (7.71 \times 10^{-5})I^2 + \ldots$$

where: Et = uncorrected potential ET (cm/mo),

Ta = mean monthly air temperature for the month of interest (°C), and

a = coefficient as a function of I.

The value of Et must then be adjusted to account for the number of days of sunlight in each month and the length of day, both of which are a function of latitude. Correction factors are available in standard hydrologic texts (e.g., Dunne and Leopold, 1978). Water losses for each month by potential evapotranspiration are then computed as the product of Et and the correction factor.

o The total discharge from the Kiggavik project area is estimated once the following data are computed:

- drainage areas for each lake in the Kiggavik study area,
- total annual precipitation, and
- response ratios for the area.

The total discharge from each watershed in the Kiggavik area may be computed by multiplying the response ratio by the total annual precipitation to give a volume per unit time per unit area (m^3 s^{-1} km^{-2}). This value can then be multiplied by the area of each watershed to give a discharge. The total discharge from the Kiggavik project area is simply the sum of all individual values from each watershed in the area. For comparative purposes, this value is compared with measured discharge values at some of the Environment Canada measuring locations into which water from the study region drains (e.g., the Aniguq River downstream of Audra Lake).

4.2.3 Data Analysis

Representativeness of Baker Lake Data

The nearest meteorological station to the Kiggavik project area is Baker Lake, which is about 75 km west. The purpose of this sub-section is to determine whether the Baker Lake data can reasonably be used to estimate conditions/inputs to the Kiggavik area.

For this analysis, mean daily air temperatures were used to assess the relationship between Baker Lake and Kiggavik area data. Hydrologic and climatological data were collected from within the Kiggavik project area during the spring to fall period of 1982 and 1983 (Roulet and Woo, 1986), and so these years were chosen for the comparison.

Daily mean air temperatures for June and July of 1982 and 1983 from both sites are listed in Tables 4.2 to 4.5, respectively. These data were compared statistically by regression analysis, and significant differences were determined by the sample size and correlation coefficient. Both regressions show a significant positive correlation ($p = 0.05$) in daily mean air temperatures recorded at both sites. For both months, the daily mean air temperature recorded at Baker Lake is approximately 10% lower than that recorded at the Kiggavik site. This is probably related to the fact that air temperature was measured at the Kiggavik site over a wetland (i.e., in a topographic low). That recorded at Baker Lake was susceptible to winds blowing across the lake, and so daily mean temperatures are slightly higher.

TABLE 4.2: MEAN DAILY AIR TEMPERATURES MEASURED IN JUNE 1982 WITHIN THE KIGGAVIK AREA AND AT BAKER LAKE

June	Kiggavik Site Mean Daily Air Temperature (°C)	Baker Lake Mean Daily Air Temperature (°C)
01	-3	-4.6
02	-4	-4.5
03	-3	-4.7
04	-3	-6.2
05	-2	-4
06	0	-0.6
07	-1	-2.9
08	-1	-4.6
09	0	-0.9
10	2	0.5
11	3	2.1
12	4	3.7
13	3	4.3
14	6	4.5
15	5.5	4.3
16	8	7.5
17	4.5	5.5
18	8	6.8
19	5	4.9
20	5.5	6.1
21	6	6
22	5	4.3
23	4.5	5.2
24	5	4.8
25	5	4.6
26	5.5	5.9
27	8	6.9
28	10	10.3
29	15	12.9
30	15	15.9
MEAN	3.9	3.1

Regression Analysis:

Constant	1.2
Standard Error of Y Estimate	0.97
R Squared (r^2)	0.96
No. of Observations	30
X Coefficient(s)	0.87
Standard Error of Coefficient	0.03

TABLE 4.3: MEAN DAILY AIR TEMPERATURES MEASURED IN JULY 1982 WITHIN THE KIGGAVIK AREA AND AT BAKER LAKE

July	Kiggavik Site Mean Daily Air Temperature (°C)	Baker Lake Mean Daily Air Temperature (°C)
01	13	11.8
02	12	10.4
03	15	15.5
04	10	9.9
05	8	8.3
06	9	9.3
07	12	12.3
08	8	9.3
09	8	7.2
10	7	8.2
11	8.5	9.4
12	10	10.8
13	12	9.7
14	11	14.1
15	10	10.3
16	10	8.5
17	12	13.6
18	15	12.4
19	16	15.1
20	8	9.1
21	9	8.8
22	15	12.2
23	20	16.1
24	17	17.1
25	16	18.1
26	15	13.2
27	14	9.4
28	13	10.1
29	12	8.1
30	10	6.8
31	9	6.4
MEAN	12	11

Regression Analysis:

Constant	2.4
Standard Error of Y Estimate	1.9
R Squared (r^2)	0.66
No. of Observations	31
X Coefficient(s)	0.85
Standard Error of Coefficient	0.11

TABLE 4.4: MEAN DAILY AIR TEMPERATURES MEASURED IN JUNE 1983 WITHIN THE KIGGAVIK AREA AND AT BAKER LAKE

June	Kiggavik Site Mean Daily Air Temperature (°C)	Baker Lake Mean Daily Air Temperature (°C)
09	3.5	0.6
10	4	2
11	4	3.8
12	5.5	4.2
13	5.5	6.3
14	5.5	7
15	5.5	3.1
16	5	5.9
17	5	5.5
18	5	5.3
19	5	5.9
20	7.5	7.7
21	8	8.4
22	10	10.7
23	9.5	10.8
24	5	6.5
25	4	3.9
26	7	9.6
27	11	12.5
28	12	14.8
29	7.5	7
30	7.5	5.7
MEAN	6.5	6.7

Regression Analysis:

Constant	2.2
Standard Error of Y Estimate	0.95
R Squared (r^2)	0.85
No. of Observations	22
X Coefficient(s)	0.65
Standard Error of Coefficient	0.06

TABLE 4.5: MEAN DAILY AIR TEMPERATURES MEASURED IN JULY 1983 WITHIN THE KIGGAVIK AREA AND AT BAKER LAKE

July	Kiggavik Site Mean Daily Air Temperature (°C)	Baker Lake Mean Daily Air Temperature (°C)
01	8	4.9
02	6	5.9
03	5	5.6
04	5	4.8
05	5	7
06	5.5	6.7
07	9	9.5
08	10	15
09	11.5	9.9
10	10	6.5
11	9	5.4
12	8.5	4.6
13	9	6.4
14	9	8.8
15	10	8.4
16	10	7.3
17	10.5	7.2
18	10.5	8.3
19	10	12.8
20	9.5	15.8
21	8	16.8
22	10.5	18
23	10	12.9
24	8.5	13.6
25	7	14.2
26	8.5	15.6
27	8.5	16.2
28	8	8.8
29	9.5	9.5
30	9	10.1
31	8	9.3
MEAN	8.6	9.9

Regression Analysis:

Constant	7.2
Standard Error of Y Estimate	1.7
R Squared (r^2)	0.11
No. of Observations	30
X Coefficient(s)	0.14
Standard Error of Coefficient	0.08

Representativeness of 1988 and 1989 Flow Data

Since all of the following analysis of surface water hydrology will be based on the 1988 and 1989 flow measurements, it is important to know how representative these years were relative to the 30-year normals for the region. This can be assessed by comparing the 1988 precipitation and air temperature records from Baker Lake to the 30-year normals (i.e., from 1951 to 1980) recorded at the same location.

The mean monthly air temperatures for 1988 and for the 30-year normals are listed in Table 4.6. There is a significant positive relation between the two sets of data, indicating that, at least with respect to mean monthly air temperatures, 1988 is a very representative year for Baker Lake records.

The 1988 and 30-year normal monthly (total) precipitation records for Baker Lake are listed in Table 4.7. The 1988 total precipitation is approximately 25% higher than the 30-year normals.

In summary then, 1988 was a fairly representative year in terms of mean monthly air temperatures, but in terms of precipitation, it was much higher than normal.

The 1989 totals are not yet available to carry out the same analysis as for the 1988 data. Total monthly precipitation from January to August is 167.4 mm for 1988, and 159.4 mm for 1989. This compares with the 142.7 mm for the 30-year normals data.

The Snowmelt Periods of 1988 and 1989

For this report, snowmelt is defined as the time the hydrographs first reported any flow (prior to peak flow) to the time the recession "levelled off" (some time after peak flow). Discharge hydrographs for each lake during 1988 and 1989 are shown in Appendix 2. For 1988, the snowmelt period was from about 08 June 1988 to about 31 July 1988. For 1989, snowmelt began on 13 June (for Cirque), 14 June (for Skinny, Escarpment and Ridge), 15 June (for Pointer) and 17 June (for Jaeger). After 31 July 1988, the hydrograph became increasingly affected by summer rain events. This timing defines the influence that an accumulated snow pack has on the hydrograph and not the time by which the majority of snow has melted on the landscape.

TABLE 4.6: MEAN MONTHLY AIR TEMPERATURES (°C) RECORDED AT BAKER LAKE

Month	1988	30-year Normals (1951-1980)
January	-34.2	-33
February	-33.5	-32.6
March	-25.6	-27.9
April	-15.7	-17.3
May	-8.5	-6.4
June	4.8	4.1
July	11.6	11
August	10.6	9.7
September	4.3	2.3
October	-6.3	-7.7
November	-22	-20.3
December	-29.9	-28.2
MEAN	-12	-12

Regression Analysis:

Constant	-0.66
Standard Error of Y Estimate	1.48
R Squared (r^2)	0.99
No. of Observations	12
X Coefficient(s)	0.96
Standard Error of Coefficient	0.03

TABLE 4.7: MEAN MONTHLY PRECIPITATION (mm) RECORDED AT BAKER LAKE

Month	1988	30-year Normals (1951-1980)
January	1.2	7.7
February	3.4	4.9
March	8.5	7.6
April	8.6	13.8
May	18.4	12
June	45.6	20.9
July	38.4	38.1
August	43.3	37.3
September	51	37
October	62.2	30.6
November	17	16.9
December	14.6	8.2
TOTAL	312	235

Regression Analysis:

Constant	5.7
Standard Error of Y Estimate	6.8
R Squared (r^2)	0.75
No. of Observations	12
X Coefficient(s)	0.53
Standard Error of Coefficient	0.10

Hydrologic Data Available for 1988 and 1989

The Kiggavik study site contains a large number of small lakes. Hydrologic data are available for six of these lakes (i.e., Ridge, Pointer, Jaeger, Skinny, Cirque and Escarpment). The following data are available:

- o snow water equivalents, and
- o lake outflow hydrographs.

Other available data include:

- o drainage basin and lake area estimates, and
- o Baker Lake meteorological records from 1951 to 1989.

Snow water equivalents for 1988 and 1989 are listed for the six watersheds in Table 4.8. Locations of snow surveys are shown in Figure 4.1. Note that in those instances where more than one transect was done, mean snow water equivalents are computed. The mean water equivalent for the whole region is approximately 0.09 m (1988) and 0.12 m (1989), which compares well with the 0.10 m 30-year normal recorded at Baker Lake.

The total volume discharged from each watershed is determined by computing the area under each hydrograph (shown in Appendix 2) for the duration of the snowmelt period. The calculated runoff volumes for each watershed are listed in Table 4.9.

Drainage basin and lake areas are estimated for each watershed in the Kiggavik study area (Table 4.1). Areal estimates are made from 1:8,000 to 1:50,000 topographical maps available for the area.

Baker Lake meteorological data are available from 1951 to 1988. Thirty-year normals (Table 4.10), 1988 data (Table 4.11) and 1989 data (Table 4.12) are used for analysis in this report.

Calculating Total Available Water

The method used for computing total available water (TAW) from each watershed in the Kiggavik area is discussed in an earlier sub-section. The following is an outline of how

TABLE 4.8: SNOW WATER EQUIVALENTS FOR SELECTED WATERSHEDS IN THE KIGGAVIK AREA

Watershed	Date of Transect(s)	Transect Water Equivalent (m) 1	2	3	4	Mean Water Equivalent (m)
1988 Surveys						
Ridge	01 June	0.09	0.06			0.08
Pointer	01 June	0.07	0.04	0.07	0.06	0.06
Jaeger	01 June	0.08	0.06			0.07
Skinny	02 June	0.10	0.15			0.13
Escarpment	02 June	0.09				0.09
MEAN						0.09

1989 Surveys

Watershed	Date of Transect(s)	Transect[1] No.	Snow-Water Equivalent (m)	Mean Snow-Water Equivalent (m)
Skinny	04 June	1	0.105	
		A	0.165	0.11
		B	0.055	
Jaeger	05 June	G	0.13	
		H	0.14	0.12
		I	0.12	
Pointer	06 June	M	0.005	
		N	0.225	
		P	0.210	0.12
		Q	0.115	
		R	0.050	
MEAN				0.12

[1] Transect locations shown in Figure 4.1.

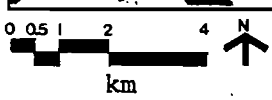
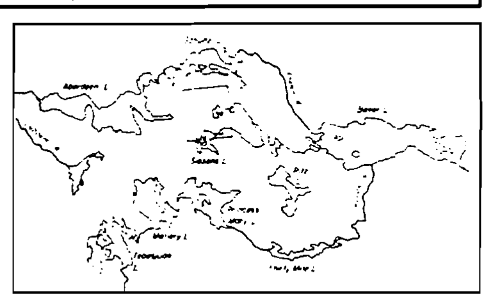


FIGURE 4.1
Location of Snow Survey Transects Carried Out in 1989



Watershed Boundary

Snow Survey Transect Lines

TABLE 4.9: RUNOFF VOLUMES[1] FROM DISCHARGE MEASURED AT LAKE OUTLETS AT SELECTED WATERSHEDS IN THE KIGGAVIK AREA

Watershed	1988 Runoff Volume* (m^3)	1989 Runoff Volume* (m^3)
Cirque	$1.1x10^5$	$1.5x10^5$
Pointer	$1.7x10^7$	$1.6x10^7$
Jaeger	$8.2x10^6$	$6.6x10^6$
Escarpment	$5.5x10^5$	$2.7x10^5$
Ridge	$3.8x10^5$	$3.3x10^5$
Skinny	$1.8x10^7$	$1.5x10^7$

[1] For the snowmelt period.

* Runoff volumes represent between 90 to 95% of the total annual runoff.

TABLE 4.10: TEMPERATURE AND PRECIPITATION NORMALS AT BAKER LAKE (1951-1980)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Temperature (°C)													
Mean	-33.0	-32.6	-27.9	-17.3	-6.4	4.1	11.0	9.7	2.3	-7.7	-20.3	-28.2	-12.2
Maximum	-29.5	-29.2	-23.7	-12.5	-2.6	7.9	16.0	13.8	5.3	-4.4	-16.4	-24.7	-8.3
Minimum	-36.4	-36.0	-32.0	-22.1	-10.2	0.2	6.0	5.5	-0.7	-11.0	-24.0	-31.6	-16.0
Precipitation (mm)													
Rainfall	0.0	0.0	0.0	0.4	5.9	18.1	38.1	36.9	31.4	7.5	T	T	138.3
Snowfall	8.0	5.4	8.3	13.6	6.3	2.8	0.0	0.4	5.9	23.2	17.4	8.7	100.0
Total Precipitation	7.7	4.9	7.6	13.8	12.0	20.9	38.1	37.3	37.0	30.6	16.9	8.2	234.6

T = Trace, less than 0.1 mm of rain or less than 0.1 cm of snow.

TABLE 4.11: PRECIPITATION AND AIR TEMPERATURE RECORDS FOR 1988 AT BAKER LAKE

1988 Mean Monthly Air Temperatures (°C)

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
-34.2	-33.5	-25.6	-15.7	-8.5	4.8	11.6	10.6	4.3	-6.3	-22	-29.9

Rain Events Occurring from June to August 1988

Date		Amount of Rain (mm)
June	03	11
	09	2.4
	10	15
	16	0.4
	29	0.4
	30	7.6
July	04	4.8
	20	0.8
	21	0.6
	22	10
	23	13.8
	27	6.4
	28	1.6
	29	0.4
August	02	1.8
	04	3.2
	05	5.8
	06	0.8
	08	0.2
	13	0.2
	14	0.8
	22	22
	23	10
	24	0.2
	25	7.4
	26	10
TOTAL		137.6

TABLE 4.12: PRECIPITATION AND AIR TEMPERATURE RECORDS FOR 1989 AT BAKER LAKE

1989 Mean Monthly Air Temperatures (^oC)

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug
-34.4	-30.0	-32.0	-17.0	-8.8	3.6	12	9.8

Rain Events Occurring from June to August 1989

Date		Amount of Rain (mm)
June	07	0.2
	08	1.8
	12	T
	14	0.8
	16	1.4
	18	9.4
	19	2.2
	21	T
	30	T
July	01	6.0
	06	0.2
	08	6.6
	12	0.2
	13	1.4
	21	0.4
	22	0.4
	23	23.6
	29	6.2
	30	14.0
August	01	4.6
	15	5.4
	16	10.8
	17	0.4
	26	0.8
	27	0.4
	29	1.4
TOTAL		98.6

T = trace amounts.

TAW is calculated for one watershed (i.e., Ridge Lake) for 1988. TAW is calculated for the other watersheds in a similar manner.

Total available water is calculated as the sum of:

- o snow water equivalent on the basin and lake (because discharge was monitored at lake outflows),
- o precipitation (occurring after the time the snow surveys were done to just before the beginning of the melt period), and
- o active layer melt from the basin.

Snow Water Equivalent

Two snow surveys were carried out on the Ridge Lake watershed on June 1/88 (Table 4.8). Mean water equivalent for this year is 0.08 m. The total area of the basin is 2.3×10^6 m^2 and lake is 1.7×10^5 m^2. The volume of water in the snowpack was computed as the product of basin area and mean water equivalent (MWE) (for the basin), and lake area and MWE (for the lake). It is assumed here that the snow depth on the basin is similar to that on the lake. Since the area is generally flat, this is a reasonable assumption. So, for Ridge Lake, the total volume of water available from the basin is 1.8×10^5 m^3, and from the lake is 1.4×10^4 m^3. The total volume available from the snowpack over the entire watershed is computed simply as the sum of these two values, or 1.9×10^5 m^3.

Precipitation

The snowmelt period is defined here from 08 June 1988 to 31 July 1988. Since the snow survey was carried out at Ridge Lake on 01 June 1988 (Table 4.8), only those precipitation events occurring after this time but before 08 June 1988 are included. Only one (11 mm) event was recorded at Baker Lake during this period (Table 4.11). This event was converted to a volume of water by multiplying by the basin area (for total basin volume) and by the lake area (for total lake volume). Precipitation from the basin is 2.5×10^4 m^3 and 1.9×10^3 m^3 from the lake, or 2.7×10^4 m^3 from the watershed.

Active Layer Melt

Because it is not possible to assess water volumes lost from the active layer using the available data, it was assumed that only 3 cm of the approximately 1 m deep active layer would be available for runoff. This was then converted to a volume by multiplying by the basin area, to give 6.9 x 10^4 m^3.

The available water from each component within each watershed for 1988 and 1989 is listed in Table 4.13.

Calculating Net Runoff

The method used for computing net runoff from each watershed is discussed in an earlier sub-section. The following is an outline of how net runoff is computed for each of the six watersheds in the Kiggavik project area where data were available. For consistency, 1988 data for Ridge Lake are given as an example. Net runoff from all others are computed in a similar manner.

Net runoff was computed as the difference between: (i) total (hydrograph) runoff (from 08 June to 31 July 1988), and (ii) total precipitation occurring between 08 June and 31 July 1988.

The total volume of water measured at the lake outlets from June 8 to July 31/88 is determined by computing the area under the hydrograph curves for this time period. For Ridge Lake, this volume is 3.8 x 10^5 m^3. The total precipitation recorded during this period was 0.064 m (Table 4.11), which is converted to a volume of water by multiplying by the basin area (for the basin volume) and by the lake area (for lake volume). For Ridge Lake, these volumes are 1.5 x 10^5 m^3 and 1.1 x 10^4 m^3, respectively. Table 4.14 lists outflow volumes and calculated precipitation volumes for each of the six watersheds in the Kiggavik study area.

It should be noted at this point that the calculated precipitation volumes are probably overestimates of what actually reaches the outflow point. This is because a portion of the incident rainfall will be intercepted or absorbed by the vegetation. Interception is probably very small because of the vegetation communities in the Kiggavik area (see

TABLE 4.13: TOTAL AVAILABLE WATER (m^3) FROM SELECTED WATERSHEDS IN THE KIGGAVIK PROJECT AREA DURING SNOWMELT

Watershed	Snow-Water Equivalents	Precipitation Inputs	Active Layer Melt	Total Available Water
1988 Data				
Ridge	1.9×10^5	2.7×10^4	6.9×10^4	2.9×10^5
Pointer	5.1×10^6	9.4×10^5	2.5×10^6	8.6×10^6
Jaeger	4.1×10^6	6.5×10^5	1.7×10^6	6.5×10^6
Skinny	1.6×10^7	1.3×10^6	3.7×10^6	2.1×10^7
Cirque	8.7×10^4	1.3×10^4	3.3×10^4	1.3×10^5
Escarpment	2.3×10^5	2.7×10^4	7.2×10^4	3.3×10^5
1989 Data				
Ridge	3.0×10^5	6.9×10^3	6.9×10^4	3.7×10^5
Pointer	1.0×10^7	2.4×10^5	2.5×10^6	1.3×10^7
Jaeger	7.6×10^6	2.5×10^5	1.7×10^6	9.6×10^6
Skinny	1.4×10^7	3.5×10^5	3.7×10^6	1.8×10^7
Cirque	1.4×10^5	2.3×10^3	3.3×10^4	1.8×10^5
Escarpment	3.0×10^5	7.1×10^3	7.2×10^4	3.8×10^5

TABLE 4.14: NET RUNOFF (m^3) FROM SELECTED WATERSHEDS IN THE KIGGAVIK AREA DURING SNOWMELT

Watershed	Outflow Volumes	Precipitation Inputs During the Melt Period	Net Runoff
1988 Data			
Ridge	$3.8x10^5$	$1.6x10^5$	$2.2x10^5$
Pointer	$1.7x10^7$	$5.4x10^6$	$1.2x10^7$
Jaeger	$8.2x10^6$	$3.8x10^6$	$4.4x10^6$
Skinny	$1.8x10^7$	$7.9x10^6$	$1.0x10^7$
Cirque	$1.1x10^5$	$7.4x10^4$	$3.6x10^4$
Escarpment	$5.1x10^5$	$1.6x10^5$	$3.5x10^5$
1989 Data			
Ridge	$3.3x10^5$	$3.2x10^4$	$3.0x10^5$
Pointer	$1.6x10^7$	$1.1x10^6$	$1.5x10^7$
Jaeger	$6.6x10^6$	$6.8x10^5$	$5.9x10^6$
Skinny	$1.5x10^7$	$1.6x10^6$	$1.3x10^7$
Cirque	$1.5x10^5$	$1.6x10^4$	$1.3x10^5$
Escarpment	$2.7x10^5$	$3.3x10^4$	$2.4x10^5$

Supporting Document No. 2) but, because no reasonable data were available on interception rates in this area, this point is simply noted.

Calculating Water Losses By Evapotranspiration

Thornthwaite

The method used for computing evapotranspirational water losses using Thornthwaite is discussed in an earlier sub-section. Mean monthly air temperatures for 1988 and 1989 are the only data required for this exercise. These are given in Tables 4.11 and 4.12, respectively.

For mean monthly air temperatures less than 0°C, the Thornthwaite method assumes no evapotranspiration. The calculated annual heat index (I) is therefore 8.43. The constant a is then 0.64 and Et for June and July 1988 is 4.90 cm/mo and 8.60 cm/mo, respectively. The correction factor for the Baker Lake site is 1.56 and 1.55 for June and July, respectively (Dunne and Leopold, 1978). Potential evapotranspirational (PET) losses for these months in 1988 are therefore 7.6 cm/mo and 13.3 cm/mo, respectively. By similar calculations, PET losses for August and September are 10.8 cm and 5.1 cm, respectively. Total seasonal PET losses for 1988 are therefore approximately 37 cm.

By similar calculations for 1989, PET losses for June, July and August are 6.8 cm, 14 cm and 11 cm, respectively, or about 32 cm for the total seasonal loss. Note that September 1989 data are not yet available.

The proportion of total surface area within the Kiggavik project area that contains lakes and vascular plants has been computed. Approximately 73% of the total Kiggavik area undergoes water loss by evaporation or transpiration. ET losses, calculated by Thornthwaite, will be adjusted by this fraction. Total ET losses (cm/mo) are converted for volumes of water by multiplying with basin areas. These are given for each of the six watersheds for 1988 and 1989, in Table 4.15.

Basin Responses to Snowmelt

The watershed runoff response ratios are a good measure of how responsive the basin is to spring melt. Response ratios are computed as net runoff divided by the total available

TABLE 4.15: WATER LOSSES FROM SELECTED WATERSHEDS IN THE KIGGAVIK AREA BY EVAPOTRANSPIRATION

Watershed	Water Losses by Evapotranspiration (m^3)			
	June	July	August	September
1988 Data				
Ridge	$1.4x10^5$	$2.4x10^5$	$2.0x10^5$	$9.5x10^4$
Pointer	$4.7x10^6$	$8.0x10^6$	$6.8x10^6$	$3.2x10^6$
Jaeger	$3.3x10^6$	$5.7x10^6$	$4.7x10^6$	$2.2x10^6$
Skinny	$6.9x10^6$	$1.2x10^7$	$1.0x10^7$	$4.6x10^6$
Cirque	$6.4x10^4$	$1.1x10^5$	$9.5x10^4$	$4.3x10^4$
Escarpment	$1.4x10^5$	$2.5x10^5$	$2.0x10^5$	$9.5x10^4$
1989 Data				
Ridge	$1.2x10^5$	$2.6x10^5$	$2.0x10^5$	
Pointer	$4.2x10^6$	$8.8x10^6$	$6.9x10^6$	
Jaeger	$2.9x10^6$	$6.0x10^6$	$4.7x10^6$	
Skinny	$6.1x10^6$	$1.2x10^7$	$1.0x10^7$	
Cirque	$5.8x10^4$	$1.2x10^5$	$9.5x10^4$	
Escarpment	$1.2x10^5$	$2.6x10^5$	$2.0x10^5$	

water. The total available water and net amounts of runoff are listed, for 1988 and 1989, for the six watersheds in the project area, in Tables 4.13 and 4.14. Response ratios range from 0.28 (for Cirque Lake in 1988) to 1.4 (for Pointer Lake in 1988). For some watersheds during each year, the response ratio is greater than unity. As this is not possible to occur, there must be errors associated with the measured or assumed terms used in computing these ratios. These results simply reflect the variable nature of snow cover, especially over tundra surfaces. Any discussion of these particular data beyond this point must remain speculative.

If these six watersheds are representative of the entire Kiggavik region, then an average response ratio for these watersheds should approximate an average for the region. The mean response ratio for 1988 and 1989 combined was 0.78 (Table 4.16), indicating that 78% of the total available water leaves the region as runoff, leaving 22% for evapotranspiration or storage.

Roulet (1985) provided a review of runoff ratios, defined here as total runoff divided by total precipitation, for Arctic watersheds. He found mean response ratios for the central Keewatin were between 0.60 to 0.75. These ratios are lower than that computed for the 1988 and 1989 snowmelt periods in the Kiggavik study area. The analysis for this report has considered only the melt period (as it is when most of the water leaves the watersheds), and so calculated response ratios will probably be higher than those estimated by Roulet (1985), who considered the entire year. Based on this fact, the mean response ratio during the melt period (i.e., 0.78) is probably quite reasonable compared with those computed by Roulet (1985) for the region.

The above calculations have shown that approximately 80% of the available water from Kiggavik leaves the region as runoff. It is now necessary to know how quickly this volume leaves the area. This may be approximated by the time it takes for the hydrograph to reach peak discharge, and can be measured directly from the hydrographs (see Appendix 2). The hydrographs show that, on average, it takes about five days for the maximum discharge to be reached after the onset of spring melt. This suggests that not only are very large volumes of water lost during the melt period, but much of it occurs within a short period of time. Watersheds in the Kiggavik project area are thus highly responsive during the snowmelt period.

TABLE 4.16: SNOWMELT RESPONSE RATIOS FOR SELECTED WATERSHEDS IN THE KIGGAVIK PROJECT AREA

Watershed	Total Available Water During Melt (TAW) (m^3)	Net Runoff During Snowmelt (NRO) (m^3)	Melt Response Ratio (NRO/TAW)
1988 Data			
Ridge	2.9×10^5	2.2×10^5	0.76
Pointer	8.6×10^6	1.2×10^7	1.4
Jaeger	6.5×10^6	4.4×10^6	0.68
Skinny	2.1×10^7	1.0×10^7	0.48
Cirque	1.3×10^5	3.6×10^4	0.28
Escarpment	3.3×10^5	3.5×10^5	1.1
MEAN			0.78
1989 Data			
Ridge	3.7×10^5	3.0×10^5	0.81
Pointer	1.3×10^7	1.5×10^7	1.2
Jaeger	9.6×10^6	5.9×10^6	0.61
Skinny	1.8×10^7	1.3×10^7	0.72
Cirque	1.8×10^5	1.3×10^5	0.72
Escarpment	3.8×10^5	2.4×10^5	0.63
MEAN			0.78

Proportional Losses of Available Water

The hydrologic character of a region may be determined by considering the amount of available water lost from the area by various pathways. This can best be accomplished by calculating water balances for each watershed (i.e., by comparing total water inputs and outputs). This can be computed for the snowmelt period and on a seasonal basis. In most natural systems, and especially in Arctic areas, water inputs and outputs are generally very difficult to correlate. There is a great deal of inherent spatial and temporal variability present in the system. This is further complicated by water measurements, which are often made under extremely adverse conditions. However, water balances are calculated for the Kiggavik area so that the relative proportion of water loss by each process may be estimated.

Water Balance for the Snowmelt Period

The total water inputs (i.e., the total available water) are listed, for each selected watershed in the Kiggavik project area for 1988 and 1989, in Table 4.17. The results show that, for all watersheds during the snowmelt periods of 1988 and 1989, total water inputs are less than the total water outputs. As this is not possible, there are errors associated with the estimates of inputs and outputs. Perhaps the most obvious source of error is the ET estimate. Computed water losses by ET are almost identical to the measured water inputs. The Thornthwaite method is, therefore, likely giving unrealistic estimates of ET. This is almost to be expected, since this method (or any other method) was not designed for use in sub-Arctic environments. A complete energy balance of the system, or an aerodynamic approach, must be undertaken. Such efforts will likely be made during the full-scale monitoring program carried out at the Kiggavik site.

Seasonal Water Balance

Seasonal water balances can be computed for each watershed as the difference between total water inputs and total outputs, for the period of 01 June to 31 August 1988. Although the thaw period lasts into September, runoff data were only available to 31 August, which limits the extent of this analysis.

TABLE 4.17: WATER BALANCES FOR SELECTED WATERSHEDS IN THE KIGGAVIK AREA DURING THE SNOWMELT

	Water Inputs (I)	Water Outputs (O)		
Watershed	Total Available Water at Melt (TAW) (m^3)	Net Runoff (NR) (m^3)	June and July Evapotranspirational Losses (ET) (m^3)	Net Change (I-O) (m^3)
1988 Data				
Ridge	2.9×10^5	2.2×10^5	3.8×10^5	-3.1×10^5
Pointer	8.6×10^6	1.2×10^7	1.3×10^7	-1.6×10^7
Jaeger	6.5×10^6	4.4×10^6	9.0×10^6	-6.9×10^6
Skinny	2.1×10^7	1.0×10^7	1.9×10^7	-8.0×10^6
Cirque	1.3×10^5	3.6×10^4	1.7×10^5	-7.6×10^4
Escarpment	3.3×10^5	3.5×10^5	3.9×10^5	-4.1×10^5
1989 Data				
Ridge	3.7×10^5	3.0×10^5	3.8×10^5	-3.1×10^5
Pointer	1.3×10^7	1.5×10^7	1.3×10^7	-1.5×10^7
Jaeger	9.6×10^6	5.9×10^6	8.9×10^6	-5.2×10^6
Skinny	1.8×10^7	1.3×10^7	1.8×10^7	-1.3×10^7
Cirque	1.8×10^5	1.3×10^5	1.8×10^5	-1.3×10^5
Escarpment	3.8×10^5	2.4×10^5	3.8×10^5	-2.4×10^5

Total (seasonal) water inputs to the Kiggavik area are calculated as the sum of snow water equivalent and precipitation occurring through the season. Total water outputs are by evapotranspiration and runoff. Values for each of these pathways have been computed for each watershed (Table 4.18).

The results are similar to those computed only for the snowmelt period, in that seasonal total water outputs exceed total inputs. The only information that can be inferred from these results is that total water inputs and outputs from the Kiggavik project area are large and probably equal on an annual basis. Runoff demands much of the available water, although evapotranspirational (ET) losses may also be significant.

Basin Responses to Summer Rains

During the summer period, the snow has generally melted and the active layer thaws to a depth on the order of 1 m deep. Evapotranspiration will be reduced because of an increase in cloudy skies and a general shortening of daylight hours. Hydrographs from each of the watersheds show rapid increases towards the middle-to-end of August 1988. The amplitude of these hydrograph rises are very much less than for the snowmelt period.

The snowmelt response (peak discharge) ranges from 7 times (for Cirque Lake in 1988) to 130 times (for Jaeger Lake in 1988) greater than the summer runoff peaks. Snowmelt peaks are, on average, 50 times greater than the summer runoff peaks. This is related to the much greater volume of water available for runoff during the spring melt period. It is evident, however, that late summer rain events can cause sporadic high flow events during this period.

Mechanisms of Runoff Production

Although the precise mechanisms of runoff cannot be defined, they may be inferred from hydrographs and knowledge of site conditions. The following is a summary of likely flow mechanisms operating throughout the year in the Kiggavik region.

<u>Spring Snowmelt</u>

During the spring melt period, large volumes of water are rapidly released to lakes and streams. This is evident by the very large hydrograph peaks recorded at lake outlets. The

TABLE 4.18: SEASONAL (JUNE TO SEPTEMBER) WATER BALANCES FOR SELECTED WATERSHEDS IN THE KIGGAVIK AREA DURING 1988 AND 1989

Watershed	Total Water Inputs (m^3) Snow Water Equivalent	Rain	Total Water Losses (m^3) ET	Runoff	Inputs-Outputs
1988 Data					
Ridge	1.9×10^5	3.4×10^5	5.8×10^5	3.8×10^5	-4.3×10^5
Pointer	5.1×10^6	1.1×10^7	2.0×10^7	1.8×10^7	-2.2×10^7
Jaeger	4.1×10^6	8.1×10^6	1.4×10^7	8.3×10^6	-1.0×10^7
Skinny	1.6×10^7	1.7×10^7	2.9×10^7	1.8×10^7	-1.4×10^7
Cirque	8.7×10^4	1.6×10^5	2.7×10^5	1.3×10^5	-1.5×10^5
Escarpment	2.3×10^5	3.5×10^5	5.9×10^5	5.9×10^5	-6.0×10^5
1989 Data					
Ridge	3.0×10^5	2.4×10^5	5.8×10^5	3.3×10^5	-3.7×10^5
Pointer	1.0×10^7	8.5×10^6	2.0×10^7	1.6×10^7	-1.8×10^7
Jaeger	7.6×10^6	5.8×10^6	1.4×10^7	6.6×10^6	-7.2×10^6
Skinny	1.4×10^7	1.2×10^7	2.8×10^7	1.5×10^7	-1.7×10^7
Cirque	1.4×10^5	1.1×10^5	2.7×10^5	1.5×10^5	-1.7×10^5
Escarpment	3.0×10^5	2.5×10^5	5.8×10^5	2.7×10^5	-3.0×10^5

almost instantaneous response of watersheds to this event suggests that much of the water moves from watersheds as overland flow, occurring when the rate of meltwater input exceeds the infiltration capacity (IC) of the soil surface. Much, if not all, of the soil is frozen, or near-frozen, at this time, thereby significantly reducing the IC of the soil surface. Response times for subsurface flows are very much lower than for overland flows (Dunne and Black, 1970ab), further suggesting an overland flow mechanism for peak discharges during spring runoff.

The recession limb of the melt hydrograph becomes progressively less influenced by overland flows as the active layer melts and the ground stores more water (i.e., the IC of the soil increases). During this period, water infiltrating into the soil can encounter a layer of low permeability (i.e., the permafrost surface) and a saturated layer can form. Once a critical depth of water is reached (defined by Darcy's Law), subsurface (saturated) flow can occur from the soil to the lakes or streams. Subsurface flows can only occur once the saturated lens develops. Subsurface flows are very much slower than surface routes because water must first percolate into the soil and be stored before the saturated lense can develop. Flow velocities are typically 1/100 to 1/1,000 of surface overland flow. As an increasing amount of water infiltrates into soils, or as the active layer deepens, the subsurface pathway contributes larger amounts of water to surface water bodies. Subsurface stormflow (SSSF) generally contributes to much of the hydrograph recession.

Early and Mid-Summer

During the early-to-mid summer period, there are no major hydrograph events. The hydrograph continues to recede as less water is available from the subsurface pathway (because the active layer can store a larger amount of water as it deepens).

Late Summer

During the late summer period, a number of sporadic (but low-volume) hydrograph peaks are evident. At low-lying areas, the capillary fringe (or tension saturated zone) and/or the water table are very near the ground surface because of the expanding active layer. As a result, a relatively small rain event can infiltrate into the soil and very quickly bring the capillary fringe and/or water table to the ground surface (Abdul and Gillham, 1984). When this occurs, a seepage face develops along the ground surface and saturation overland flow (SOF) can occur. A seepage face at atmospheric pressure results in outwardly-directed hydraulic gradients from the soil (Gillham, 1984), thereby causing water from within the soil to quickly leave by this route. In addition, any precipitation falling directly onto the saturated areas can move as overland flow to surface waters. The mechanisms of return flow and precipitation onto saturated areas are known collectively as saturation overland flow.

Summary

During the spring snowmelt period, overland flow (HOF), initiated when meltwater rates exceed the frozen soil IC, is responsible for hydrograph peaks, while subsurface stormflow (SSSF), initiated after a saturated lens develops above an impermeable frost surface in the soil, generates the recession limb of the hydrograph. During early-to-mid summer, few events are recorded on hydrographs because of evapotranspirational losses and because there is much storage within the system (i.e., in wetlands and the active layer). The rainy period of late summer can cause sporadic high flows by saturation overland flow (SOF), that is, by development of a seepage face in low-lying areas. All of the above mechanisms result in a rather complex, hydrologically responsive system within the Kiggavik area.

Discharges From the Kiggavik Project Area

<u>Annual Discharges</u>

The water budgets of several local watersheds must be known for estimating dilution and dispersion of any liquid discharges, and for predicting impacts in watersheds that are to be affected by site development. On an annual basis, water budgets can be estimated using:

- the total annual precipitation,
- the total watershed area, and
- the watershed response ratio.

The total annual precipitation for 1988 was 312 mm; the mean response ratio for watersheds in the Kiggavik area for the year was calculated to be 0.78, and watershed areas are listed in Table 4.1. Calculated discharges for major watersheds in the Kiggavik region are shown (for 1988) in Figure 4.2.

The total 1988 precipitation from January to September was 167.2 mm. The corresponding amount for 1989 was 159.4 mm. Total annual precipitation for 1988 was 312 mm, so assuming a similar relationship between total precipitation up to September, and total annual precipitation, an estimated total annual precipitation for 1989 is 297 mm. This value was used to estimate discharges from each watershed in the Kiggavik area. The 1989 discharges for each watershed are shown in Figure 4.3. For comparative purposes, the 30-year mean discharges are given for each of the Kiggavik area watersheds in Figure 4.4.

An Environment Canada streamflow gauging station is located on the Aniguq River just downstream of Audra Lake. Estimated mean discharge (using the above technique) is 25.1 m^3/s for 1988 and 23.9 m^3/s for 1989. These are reasonably similar to the measured mean discharge from May to December of 28 m^3/s between 1985 and 1987 (IWD, Yellowknife).

The discharge from the Kiggavik project area, estimated by the outflow from Pointer Lake, averages about 0.66 m^3/s on an annual basis. This represents about 2% of the total flow of the Aniguq River at the point of discharge into Baker Lake. For most of the year, the smaller streams and surface soil are frozen and discharges become negligible. Most of the streamflow occurs in spring and summer, when the rate of precipitation is highest and runoff is free to flow overland and through the unfrozen surface soil, and Environment Canada (1986) streamflow data for the Aniguq River downstream of Audra Lake indicate zero discharges for the months of December to May, inclusive. Monthly average flows increased to about 100 m^3/s in June, fell to 46 m^3/s between July and September, and then to less than 1 m^3/s in November. Streamflows thus vary widely on a seasonal basis. This information on the annual hydrologic response of the Kiggavik region is critical in evaluating the effects of any site development on local and regional water quality.

FIGURE 4.2
Schematic Representation of Annual Drainage at Kiggavik During 1988

All Figures are in Cubic Meters per Second

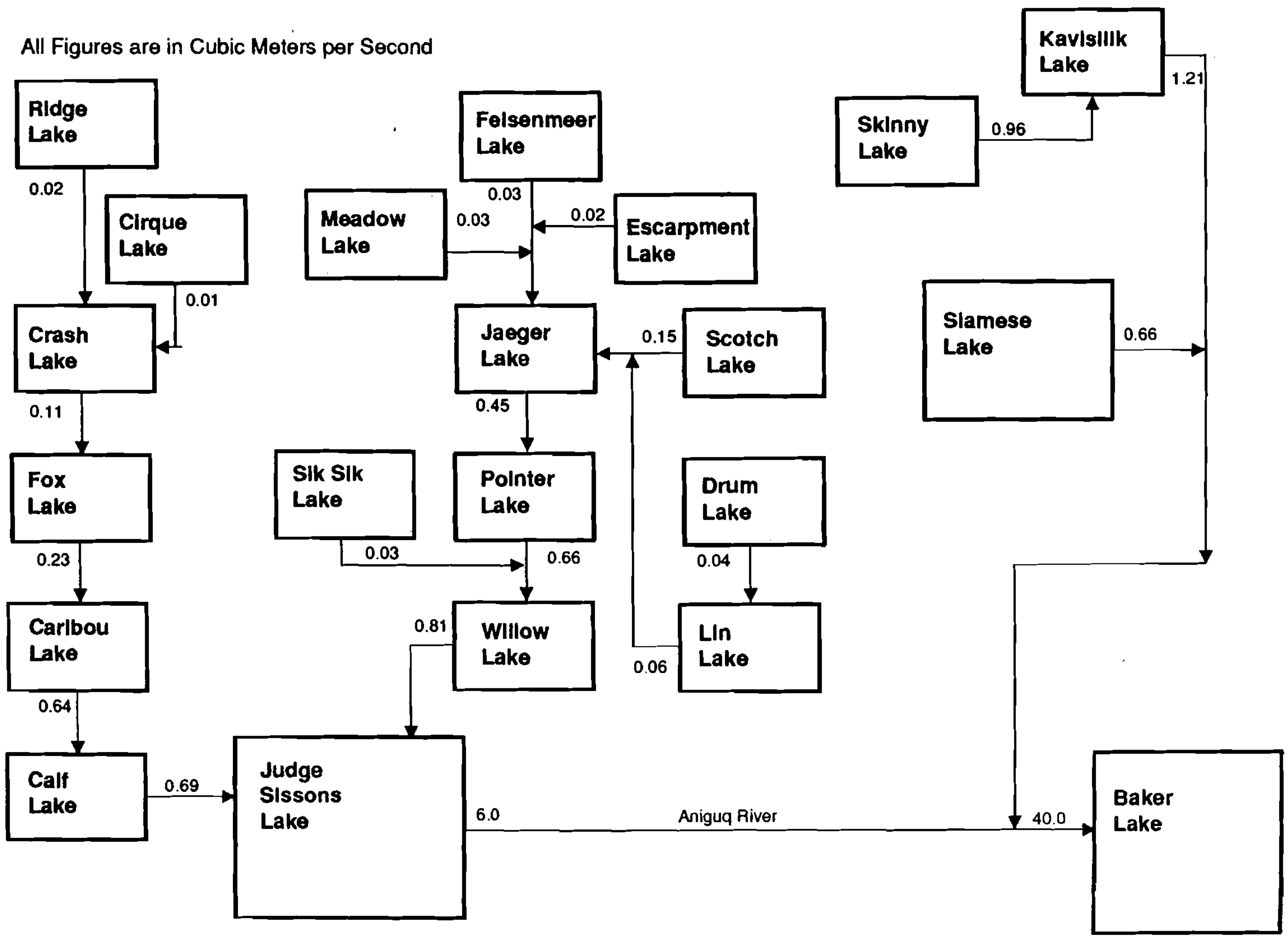


FIGURE 4.3
Schematic Representation of Annual Drainage at Kiggavik During 1989

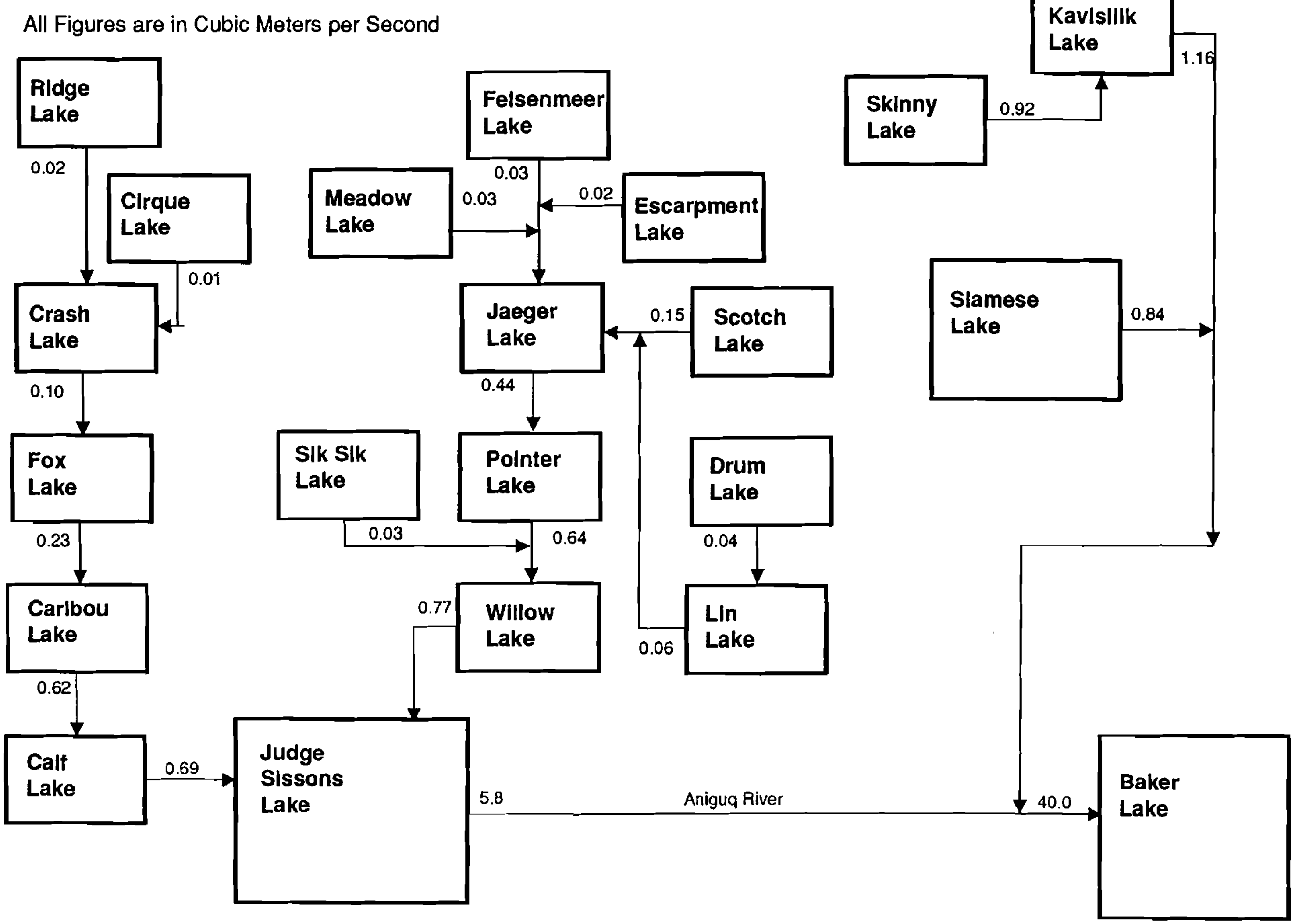
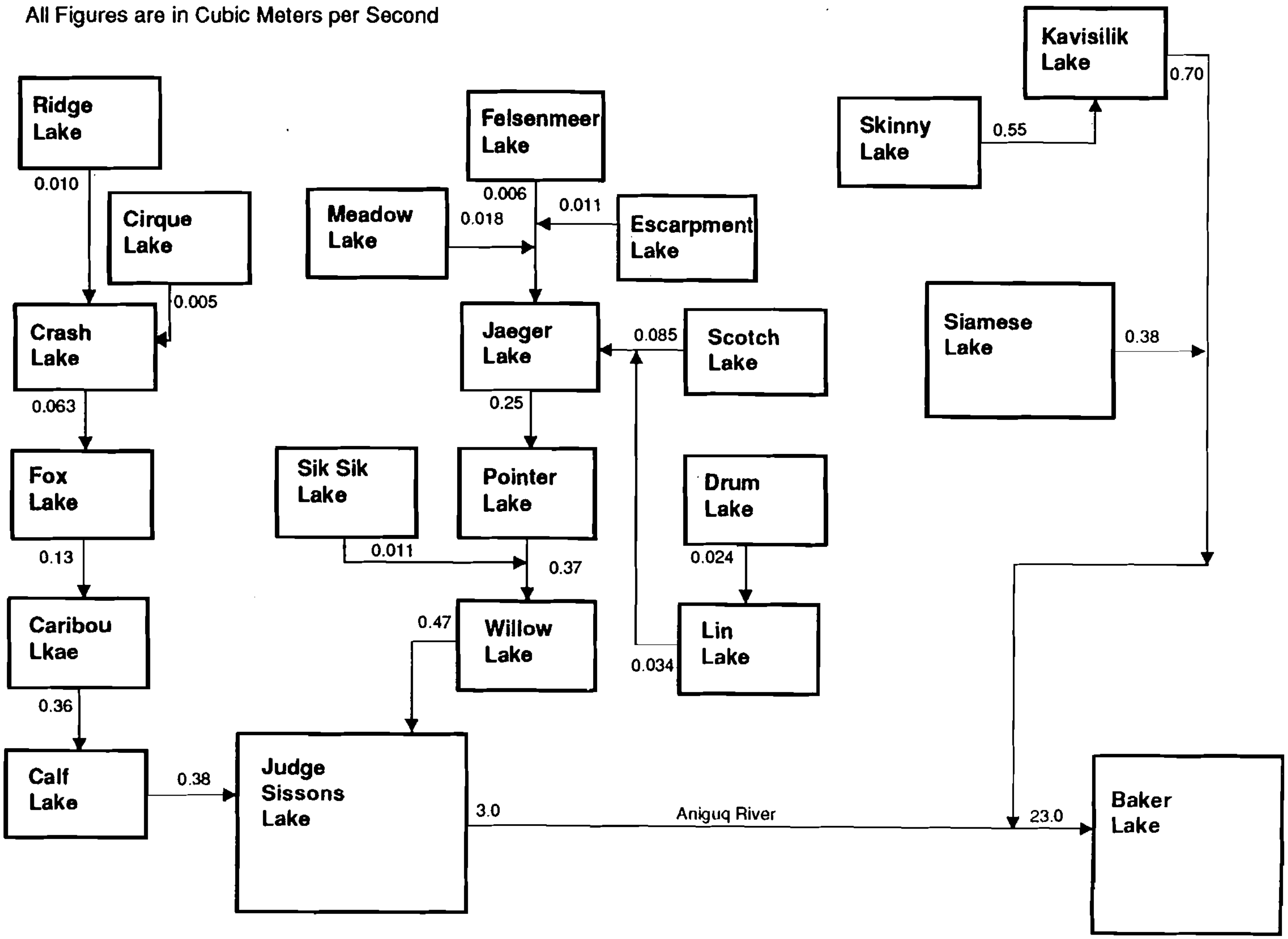


FIGURE 4.4
Schematic Representation of the 30 Year Mean Drainage at Kiggavik

All Figures are in Cubic Meters per Second



Discharges During The Snowmelt Period

The preceding analysis allowed for determination of regional hydrology on an annual basis. It would be of interest to calculate regional discharges only for the snowmelt period, and to compare these with the annual discharges.

Total discharges from the Kiggavik area during the snowmelt period can be estimated using the values of net runoff computed for the six monitored watersheds. By dividing the net runoff during snowmelt by the watershed areas, a mean value of runoff per unit area can be calculated. This value is 9.8×10^4 m^3/km^2 (for 1988) and 1.3×10^5 m^3/km^2 (for 1989).

The average snowmelt discharge from the entire Kiggavik region during the 1988 and 1989 snowmelt periods is therefore 7.8×10^7 m^3, and represents about 7% of the total flow of the Aniguq River at the point of discharge into Baker Lake. This proportion is similar to the annual proportion largely because the snowmelt period dominates much of the hydrologic activity in the Kiggavik area for the year.

Assumptions and Potential Sources of Error

A number of assumptions were made for this analysis. There are also potential sources of error in the measurement of various characteristics of the system (i.e., basin and lake areas, outflow discharges, etc.). These will be discussed in the following sections.

Basin and Lake Areas

One potential source of error in this analysis is the value used for basin and lake areas. Because all water depths were converted to volumes by multiplying with basin and lake areas, any error in estimating these areas will be incorporated into each step of the analysis. As discussed in a previous section, areas were estimated from 1:8,000 to 1:50,000 topographic maps available for the region. No specific allowance was made for local snow pack anomalies. Small watershed areas (such as Cirque Lake) may be expected to show significant deviations from the mean for the region. These anomalies are useful, however, in that site modifications such as building construction, pit development, waste rock piles, etc. will all result in local drifting of snow and shift local watershed response from the Pointer Lake watershed response more toward the Cirque Lake watershed response.

Baker Lake Data

Although the Baker Lake data have been shown to be similar to estimates made in the Kiggavik site, the relationships are not 1:1 and have been assessed only for 2 months of 2 years. Roulet and Woo (1986) measured various hydrologic and meteorological parameters at a small lake (i.e., Crash Lake) within the Kiggavik region. The representativeness of this one location to the entire region has not been shown. Furthermore, there were no available data with which to compare precipitation inputs. These are likely to be at least as variable between the Kiggavik area and Baker Lake as air temperature. Since both air temperature and precipitation inputs from Baker Lake were used in this analysis, more comparisons between the two locations should be made in the future.

Snow Water Equivalents

Snow water equivalents for each watershed were, for 1988, generally taken from one snow survey. A much greater number of transects would be required, at least for the larger watersheds, to more precisely determine the water equivalent and to allow for a better comparison with the 1989 data. It would also be useful to carry out surveys during the melt period so that direct comparisons could be made between water equivalents and watershed runoff.

Snowmelt Period and Runoff

It was assumed that the spring melt period started when the hydrograph first responded and continued until 31 July 1988. Because discharge was measured at lake outlets, a significant volume of snow may have melted prior to the time the hydrograph first responded. This volume may not have reached the flow monitoring location because of retention on the lake surface. This will introduce a lag time, which will influence the time-to-peak and other hydrologic characteristics of the watershed, such as response ratios. Because of these lags, the upstream portions of the Kiggavik study area watersheds may even be more responsive than these downstream data show.

4.2.4 Predictions of Surface Water Responses During Snowmelt

The preceding analysis has revealed some interesting aspects of the surface water hydrology in the Kiggavik project area. Of particular interest is the fact that snowmelt generates a large and rapid response, and so controls the hydrologic character of the region. This information is critical for evaluating potential effects associated with land use changes.

In most cases, knowledge of the probable responses to events of varying size and recurrence are a necessary prerequisite for planning purposes. That is, engineering and geomorphic structures are designed to account for system responses to some large infrequent event. Predicting the occurrence of these events, and associated system responses, is therefore necessary.

The following is an exercise designed for predicting surface water responses to snowmelt events occurring with a given recurrence interval. Total annual precipitation will be used to characterize inputs generating a given snowmelt. The analysis is based on sound fundamental hydrologic principles, but is extended beyond normal limitations to allow for a full interpretation for predictive purposes.

The analysis is carried out by the following logic and assumptions. Earlier sub-sections have outlined surface water responses to hydrologic conditions (i.e., snowmelt release) dictated by a total annual precipitation of 312 mm (1988) and 297 mm (1989). Assuming a direct proportional relationship between total inputs, precipitation and volumes of snowmelt, then if total precipitation inputs were to change (i.e., from one year to the next), system responses (to a different volume of snowmelt) would change accordingly. If it were possible to predict the total annual precipitation responsible for a snowmelt event with a given recurrence interval (or probability), then surface water responses to these events could be predicted (using the 1988 and 1989 responses as a reference).

For this analysis, surface water responses to snowmelt events of a given size will be defined as the total volume of runoff during the snowmelt period.

Predicting the Total Annual Precipitation Responsible for a Snowmelt Event of a Given Magnitude and Recurrence

As discussed above, system responses to snowmelt events of a given size (and recurrence interval) can be determined if the total annual precipitation, responsible for such events, can be predicted.

It may be necessary at this point to discuss what is meant by a "snowmelt event of a given size and recurrence interval". One may wish to know the hydrologic response to a 50-year snowmelt event. This does not refer to a snowmelt event of a given size occurring once every 50 years, but instead refers to the probability of occurrence of an event of a given magnitude. For a 50-year snowmelt event, the probability of occurrence is 2%. Two 50-year snowmelt events can occur in successive years, although the probability is extremely low. These melt events are generated in years having a given total annual precipitation. The purpose of this exercise is to be able to predict the total annual precipitation responsible for snowmelt events of a given magnitude and return period.

For this exercise, the total annual precipitation is required for all available years of record. The analysis is generally reserved for extreme value distributions, but may be modified for this exercise. Note that, because total annual precipitation was not yet available for 1989, it was not included in the analysis. Table 4.19 lists total annual precipitation recorded at Baker Lake from 1952 to 1988. The recurrence interval (T) of each precipitation total is computed as follows:

- o all precipitation totals are ranked by size. The largest event is ranked m=1 and the smallest is ranked m=n, where n is the number of years of record;
- o if several precipitation totals are the same, each is assigned the same rank; for example, if three years have the same total precipitation which should have been ranked 4,5,6, the rankings are then 1,2,3,5,5,5,7;
- o a return period (recurrence interval) is computed for each precipitation total as:

$$T = \left[\frac{n+1}{m}\right]$$

TABLE 4.19: TOTAL ANNUAL PRECIPITATION AND RECURRENCE INTERVALS FOR BAKER LAKE RECORDS (1952-1988)

Year	Total Precipitation (mm)	Rank (m)	Recurrence Interval (T)
1952	232	23.0	1.65
1953	207	29.0	1.31
1954	154	37.0	1.03
1955	295	10.0	3.80
1956	183	32.5	1.17
1957	182	34.0	1.12
1958	228	26.0	1.46
1959	247	19.0	2.00
1960	208	28.0	1.36
1961	230	24.0	1.58
1962	250	17.0	2.24
1963	191	31.0	1.23
1964	193	30.0	1.27
1965	176	35.0	1.09
1966	173	36.0	1.06
1967	300	9.0	4.22
1968	274	11.0	3.45
1969	214	27.0	1.41
1970	316	4.0	9.50
1971	250	17.0	2.24
1972	183	32.5	1.17
1973	243	21.0	1.81
1974	264	14.0	2.71
1975	334	3.0	12.67
1976	236	22.0	1.73
1977	363	2.0	19.00
1978	266	12.0	3.17
1979	246	20.0	1.90
1980	250	17.0	2.24
1981	229	25.0	1.52
1982	314	5.0	7.60
1983	265	13.0	2.92
1984	257	15.0	2.53
1985	369	1.0	38.00
1986	312	7.5	5.07
1987	313	6.0	6.33
1988	312	7.5	5.07

The recurrence interval and associated precipitation totals are plotted as natural logarithm of T vs total annual precipitation in Figure 4.5. The relationship is a significant one (r^2=0.91, n=37) although not simply linear. However, a best-fit line can be made for predictive purposes.

Now that the annual precipitation inputs generating snowmelt events of a given return period can be predicted, the system responses to these events can now be determined. The system response was defined as the total volume of water released as runoff during the snowmelt period because snowmelt is the single largest hydrologic event of the year. All other times of the year are comparatively hydrologically inactive.

Predicting Watershed Discharges in Response to Snowmelt Events of a Given Magnitude and Return Period

Surface water responses to specific snowmelt events are determined by considering the following information about individual watersheds in the Kiggavik study area:

- o net runoff (calculated as the total discharge through lake outflows during snowmelt, minus any precipitation occurring during this period);
- o total depth of water available as snowmelt (calculated as the ratio between the total available water and total watershed area);
- o total watershed area (calculated as the sum of basin and lake areas); and
- o total annual precipitation.

Predictive equations can be developed for each watershed in Kiggavik where data are available, and then averaged to allow for prediction of hydrologic responses for the entire Kiggavik region. These equations are most useful for predictive purposes if they are simplified for unit system characteristics. For this exercise, an equation is developed to allow for prediction of total runoff during snowmelt for a unit depth of available water; a unit watershed area, and for 100 mm of total annual precipitation. That depth of total annual precipitation was chosen for simplification of later computations.

For each watershed, the net runoff, total available water and total annual precipitation input are tabulated (Table 4.20). The total volume of runoff during snowmelt is

FIGURE 4.5
Recurrence of Total Annual Precipitation of a Given Magnitude

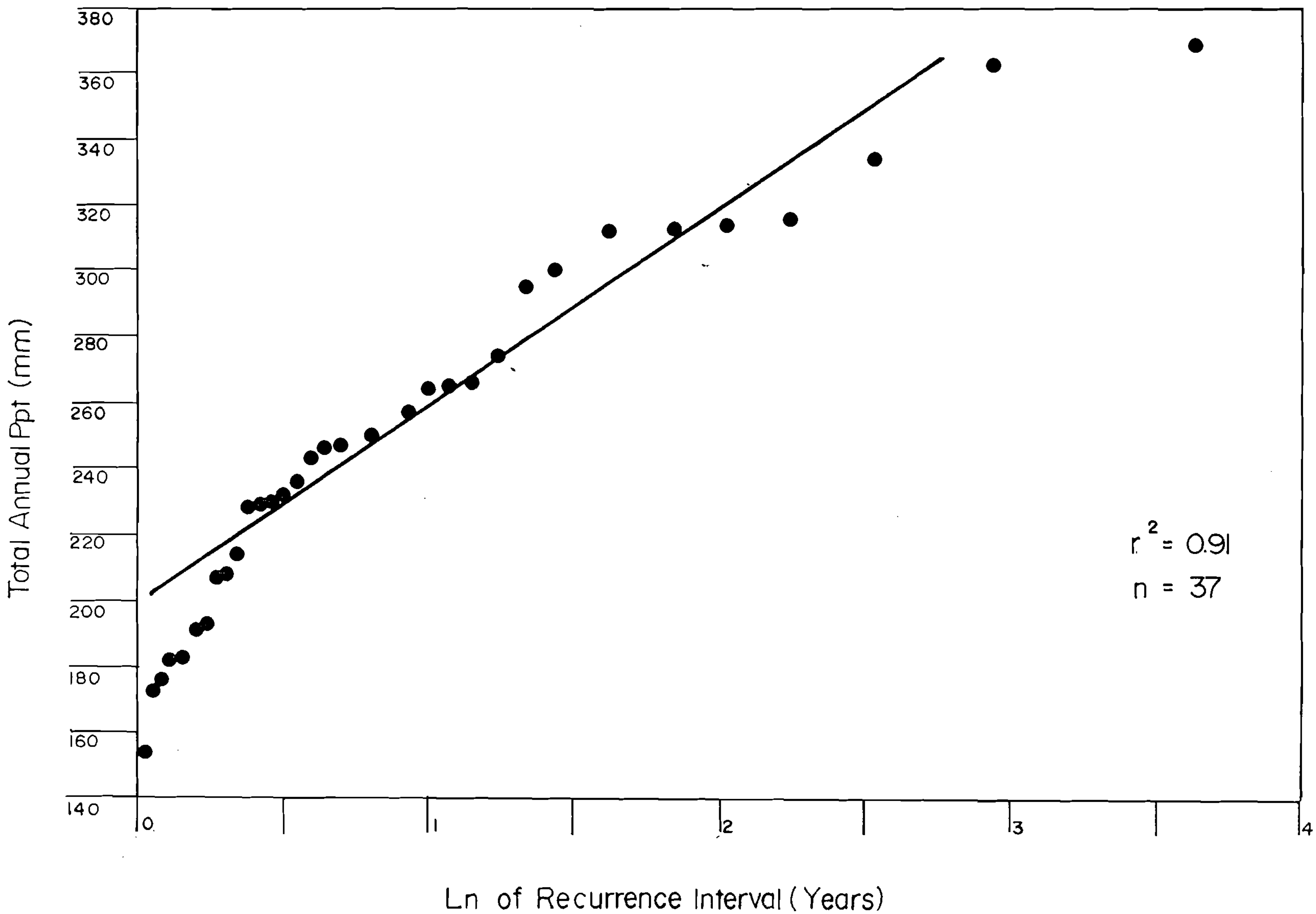


TABLE 4.20: SUMMARY OF HYDROLOGIC DATA FOR SELECTED WATERSHEDS IN THE KIGGAVIK PROJECT AREA

Watershed	Net Runoff (m^3)	Total Available Water (m^3)	Total Area (Lake + Basin) (m^2)	Total Annual Precipitation (mm)
1988 Data				
Ridge	2.2×10^5	2.9×10^5	2.5×10^6	312
Pointer	1.2×10^7	8.6×10^6	8.6×10^7	312
Jaeger	4.4×10^6	6.5×10^6	5.9×10^7	312
Skinny	1.0×10^7	2.1×10^7	1.2×10^8	312
Cirque	3.6×10^4	1.3×10^5	1.2×10^6	312
Escarpment	3.5×10^5	3.3×10^5	2.5×10^6	312
1989 Data				
Ridge	3.0×10^5	3.7×10^5	2.5×10^6	297
Pointer	1.5×10^7	1.3×10^7	8.6×10^7	297
Jaeger	5.9×10^6	9.6×10^6	5.9×10^7	297
Skinny	1.3×10^7	1.8×10^7	1.2×10^8	297
Cirque	1.3×10^5	1.8×10^5	1.2×10^6	297
Escarpment	2.4×10^5	3.8×10^5	2.5×10^6	297

computed for a watershed area and for the equivalent depth of annual precipitation by dividing the runoff volume by each respective term. For example, the Ridge Lake watershed, having an area of 2.5×10^6 m^2 and 0.312 m of total annual precipitation, lost 2.2×10^5 m^3 of water as runoff during the 1988 snowmelt year. The predictive equation would be: $2.2 \times 10^5/2.5 \times 10^6/0.312$, or 0.28 $m^3/m^2/m$. The equations for the other watersheds are as follows:

		1988 Data	1989 Data
o	Ridge:	0.28 $m^3/m^2/m$	0.40 $m^3/m^2/m$
o	Pointer:	0.45 $m^3/m^2/m$	0.59 $m^3/m^2/m$
o	Jaeger:	0.24 $m^3/m^2/m$	0.34 $m^3/m^2/m$
o	Skinny:	0.27 $m^3/m^2/m$	0.36 $m^3/m^2/m$
o	Cirque:	0.10 $m^3/m^2/m$	0.36 $m^3/m^2/m$
o	Escarpment:	0.45 $m^3/m^2/m$	0.32 $m^3/m^2/m$

The mean coefficient for these watersheds (representing a mean for the entire Kiggavik region) for 1988 and 1989 is 0.35.

The surface water response to a 55-year snowmelt event may thus be determined for a given watershed in the Kiggavik area (or for the entire region) as follows.

A 55-year snowmelt event corresponds to an annual total precipitation of about 370 mm (Figure 4.5). Supposing that the watershed of interest is Judge Sisson's Lake, the total area is 6.8×10^8 m^2. The total runoff from the Judge Sissons watershed during the snowmelt period, for hydrologic conditions associated with a 55-year snowmelt event, is therefore calculated as:

$$0.35 \; m^3/m^2/m \times 6.8 \times 10^8 \; m^2 \times 0.37 \; m = 8.8 \times 10^7 \; m^3$$

This value is similar to the estimated 1988 and 1989 discharges from Kiggavik, suggesting that the snowmelt events of these years were similar in magnitude to a 55-year snowmelt event. This is a good assumption as the total annual precipitation in 1988 and 1989 was about 80 mm and 60 mm higher, respectively, than the 30-year normals for Baker Lake.

4.2.5 Summary and Implications for Site Development

The preceding analysis has outlined some important features of the surface water hydrology in the Kiggavik project area. There are generally three hydrologic periods during the year and each is characterized by distinct responses and flow mechanisms. The most important of these, hydrologically, is the spring snowmelt period, in which large volumes of water are lost from watersheds over very short periods of time, probably by overland flow. Response ratios are high at this time, indicative of an overland flow mechanism. Early and mid summer is a time with minimal amounts of runoff because of evaporative losses and water storage in the expanding active layer and in wetlands. Late summer is a period of sporadic rain events and, because of restricted evapotranspiration and thawed soils, surface waters can be responsive to these rain events because of saturated overland flows.

This discussion of flow mechanisms is speculative because detailed hydrologic investigations have not been made in the area to support such statements. However, they are based on fundamental knowledge of site conditions and measured hydrologic responses, and so are probably reasonable estimates.

A model is presented for predicting snowmelt runoff in response to given annual precipitation inputs. This analysis is also speculative, but offers approximations in an area with limited data. Snowmelt runoff can be predicted if the watershed area and total annual precipitation are known.

The rapid response of the Kiggavik study area, and the large volumes of water released during snowmelt, suggest that much of the region is hydrologically connected, so that changes in one watershed will likely affect all others. This is especially relevant for the area just west of Pointer Lake, which is characterized by a large number of small lakes and wetlands. In terms of site development, there are a number of points that require attention. Because the region is highly responsive during the snowmelt period, any activities that involve changing surface conditions within a watershed should be evaluated as to their effect on runoff. If significant changes are made that affect runoff during this period, hydrologic conditions throughout the region will be affected. The same applies, although much less so, for very late summers, when the surface water hydrology is responsive to rain events. The most appropriate time to develop site conditions is either after the late summer period or during the early-to-mid summer (i.e., after the snowmelt period). Hydrologic activity is reduced and changes to site conditions will probably have only local effects. The significant point here is to avoid significant surface area changes during the snowmelt period. After this period, the Kiggavik region is hydrologically much less responsive to precipitation inputs and so site development will likely have less effect than during the snowmelt period.

Site modifications such as building construction, pit development, construction of waste rock piles, etc. will result in local drifting of snow. This will contribute to runoff peaks, although volumes will be reduced, as the snowmelt period is extended.

4.3 Flushing Rates for Lakes in the Kiggavik Area

Flushing rates, or retention times, were computed for each lake in the Kiggavik area using the bathymetry maps and mean depths given in Appendix 1 and the 30-year normal flow data outlined in Figure 4.4. Retention times are important characteristics of lakes because they affect water quality. Lakes with short retention times are less likely to be affected by contaminants than those lakes with long retention times where the water is not frequently mixed or replaced. In the Kiggavik area, lakes with a relatively large volume-to-drainage area ratio have longer residence times than lakes with a small volume-to-drainage area ratio (Table 4.21). Thus, on an average annual basis, Crash Lake flushes every 16 days, while Scotch Lake flushes only once every 2.7 years. Judge Sissons Lake is relatively large and deep, and flushes only once every 4.7 years.

4.4 Regional Hydrology

Discharges from the Kiggavik project area can best be assessed by considering the magnitude relative to the regional discharges through the area. Kiggavik area drainage, approximated by the streamflow at the outlet of Pointer Lake, averages about 0.66 m^3/s on an annual basis. Water then flows along the Aniguq River, where it drains into Baker Lake at about 40 m^3/s. The Thelon River and Kazan River also drain into Baker Lake, with mean annual discharges of 810 m^3/s and 410 m^3/s, respectively. Water passes through Baker Lake at about 1,300 m^3/s and then through Chesterfield Inlet at 1,500 m^3/s, eventually discharging through Hudson Bay at approximately 17,000 m^3/s.

TABLE 4.21: CALCULATION OF FLUSHING RATES FOR KIGGAVIK AREA LAKES

Lake	Surface Area (ha)	Lake Volume[1] (m^3)	Annual Discharge[2] (m^3/s)	Retention Time (yr)
Ridge	16.7	$3.8x10^5$	0.010	1.2
Cirque	5.6	$1.5x10^5$	0.0049	0.97
Crash	8.1	$8.7x10^4$	0.063	0.04
Fox	128	$2.2x10^6$	0.13	0.54
Caribou	341	$4.9x10^6$	0.36	0.43
Felsenmeer	20.8	$4.2x10^5$	0.0063	2.12
Escarpment	13	$2.8x10^5$	0.011	0.81
Meadow	14	$1.2x10^5$	0.018	0.21
Drum	25	$3.3x10^5$	0.024	0.44
Lin	48	$6.3x10^5$	0.034	0.59
Scotch	201	$7.1x10^6$	0.085	2.66
Jaeger	281	$4.6x10^6$	0.25	0.59
Pointer	374	$5.6x10^6$	0.37	0.48
Sik Sik	16	$1.3x10^5$	0.011	0.38
Willow	55	$7.7x10^5$	0.47	0.05
Judge Sissons	9,550	$4.4x10^8$	3.0	4.66
Skinny	197	$6.1x10^6$	0.55	0.35
Kavisilik	564	$2.4x10^7$	0.70	1.09

[1] Calculated as mean water depth x lake area.

[2] Using 30-year normals data from BEAK (1988).

In summary, the mean annual discharge from the Kiggavik study area represents about 2% of the Aniguq River discharge to Baker Lake, 0.05% of the total discharge into and out of Baker Lake, 0.04% of the discharge from Chesterfield Inlet and 0.004% of the discharge from Hudson Bay. The Kiggavik study area drainage therefore represents a relatively small proportion of the regional discharge.

4.5 Monitoring Implications

An accurate account of local hydrologic conditions will be required in the ongoing monitoring program carried out at the mine so that releases of materials to the aquatic environment can be traced through the system, and compliance with operating licences demonstrated. For a release of process effluent at the outlet of Pointer Lake, as planned, hydrologic conditions will require monitoring in the Pointer Lake outlet stream. Runoff should also be monitored at the Judge Sissons outlet, as this is considered to be the interface between the local environment and the regional environment. The continuous collection of meteorological data at the project site will also enable the mine operators to better project the magnitude of runoff from the project area.

5.0 SURFACE WATER AND GROUNDWATER QUALITY

5.1 Physical Characteristics

Surface waters in the Kiggavik study area are ice-covered for most of the year, with ice forming in September and disappearing in June (in smaller lakes) or July (in larger lakes). Judge Sisson's Lake is slower to warm and lose its ice cover than most Kiggavik study area lakes because it is much larger and contains a greater amount of ice on the surface. Based on observations in the Kiggavik study area, the maximum ice thickness is about 2 m.

Kiggavik area lakes are cold, monomictic lakes, that is, vertical mixing occurs only during the brief ice-free season of two to three months in summer. In contrast, more temperate lakes become thermally stratified in summer, with a warm surface layer (epilimnion) forming over a cold, deep layer (hypolimnion), with the two layers separated by a thermocline. The absence of thermal stratification in Kiggavik area lakes during the summer can be related to the low heat input in combination with the high winds that frequently prevail during the ice-free season.

Figure 5.1 provides temperature and dissolved oxygen profiles for Judge Sisson's Lake, and Table 5.1 lists lake temperature and dissolved oxygen data for selected Kiggavik area lakes. Judge Sisson's Lake may warm to as high as 12°C in summer, while shallower lakes, such as Pointer Lake, can reach temperatures of 16°C. Temperatures show little variation with depth during the summer ice-free period. Some degree of thermal stratification does occur under-ice however, as shown in the 17 June plot for under-ice conditions (Figure 5.1). Water reaches its maximum density at about 4°C and colder water lying next to the surface ice layer "floats" on the warmer, denser underlying water mass.

Kiggavik area lakes tend to be very transparent, reflecting low levels of biological productivity and low rates of sediment input. Secchi disk transparencies were measured on several occasions in 1979, and were always found to be greater than maximum lake depths when measured in Pointer Lake, Jaeger Lake and Scotch Lake. Transparencies ranged between 7 and 8.5 m in Sisson's Lake during the same year, reflecting low levels of colour and suspended particulates. It should be noted, however, that in relatively

FIGURE 5.1
Dissolved Oxygen and Temperature Profiles in Judge Sissons Lake- 1980

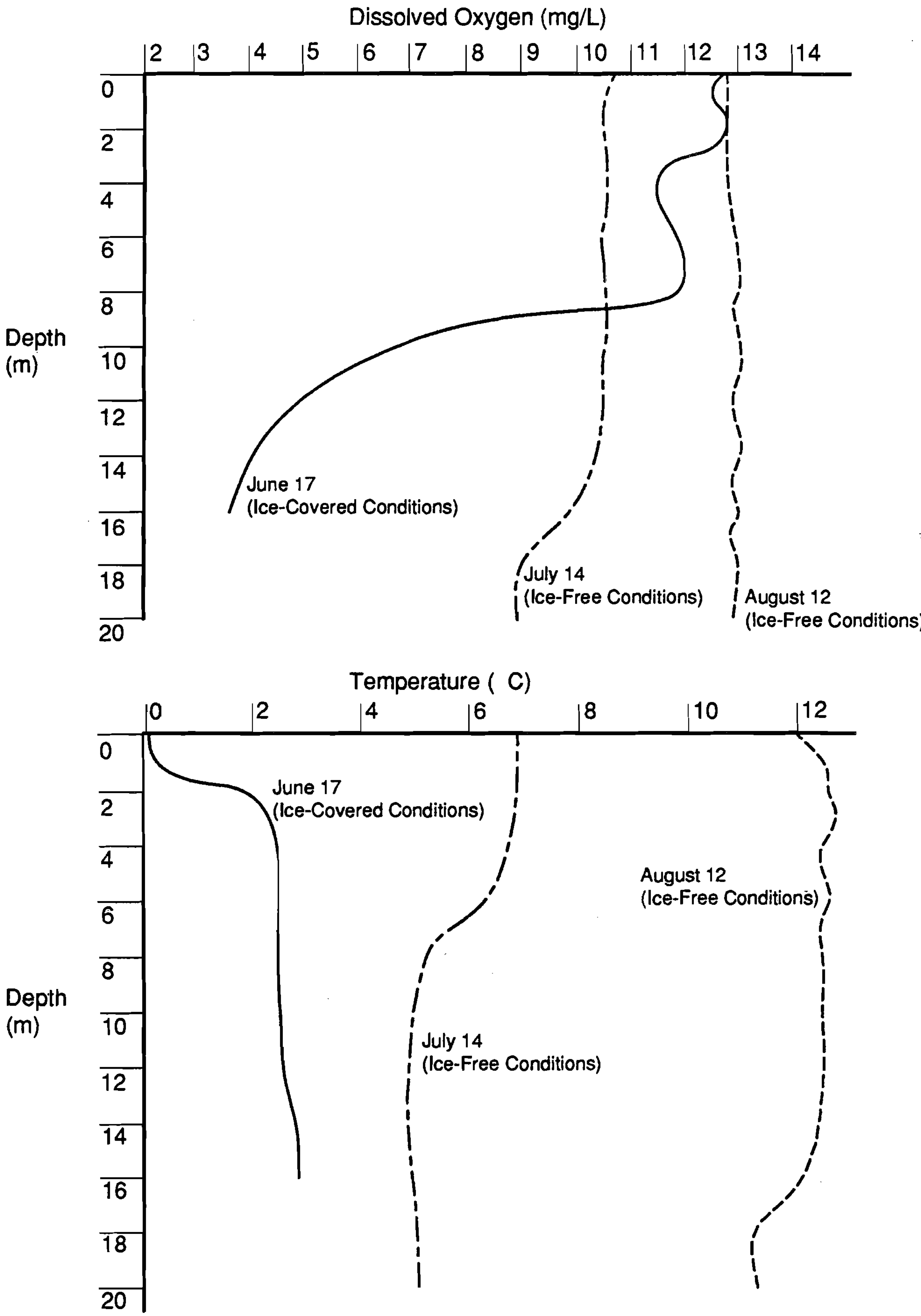


TABLE 5.1: TEMPERATURE AND DISSOLVED OXYGEN DATA FOR SELECTED KIGGAVIK AREA LAKES, 1979 AND 1980

Location	Date (1979)	Depth (m)	Temp. (°C)	Dissolved Oxygen (mg/L)	Location	Date (1980)	Depth (m)	Temp. (°C)	Dissolved Oxygen (mg/L)
Pointer Lake	21 Jun	-	-	-	Pointer Lake	14 Jun	2	0.5	12.2
(deep area)	03 Jul	1	1.3	11.3	(deep area)	10 Jul	1	11.4	11.3
	06 Jul	1	4.9	11.2		10 Jul	2	11.4	11.2
	16 Jul	-	-	-		05Aug	1	15.4	10.1
	19 Jul	1	10.0	10.2		05 Aug	2	15.4	10.1
	24 Jul	1	8.5	11.0					
	31 Jul	1	7.5	10.9	Pointer Lake	28 Jun	-	5.2	12.5
	03 Aug	1	8.5	11.0	(outlet)	05 Aug	-	16.3	9.8
	07 Aug	1	8.5	11.3					
	25 Aug	1	7.0	11.2					
Scotch Lake	27 Aug	1	6.0	11.4	Scotch Lake	17 Jun	1	0.8	12.2
(deep area)	27 Aug	4	6.0	11.0	(deep area)	17 Jun	6	3.6	6.8
						23 Jul	1	11.5	10.5
						23 Jul	6	11.6	10.4
						15 Aug	1	14.6	10.1
						15 Aug	6	14.4	10.0
					Scotch Lake (outlet)	06 Aug	-	16.3	10.0
Sisson's Lake	10 Aug	1	7.0	10.9	Sisson's Lake	17 Jun	1	0.2	12.6
(deep area)	10 Aug	19	7.0	10.8	(deep area)	17 Jun	18	2.8	3.7
	16 Aug	1	8.3	10.8		14 Jul	1	6.9	12.8
	16 Aug	18	7.9	11.2		14 Jul	19	5.0	12.9
	24 Aug	1	8.3	10.6		12 Aug	1	12.5	10.6
	24 Aug	18	8.3	10.6		12 Aug	19	11.1	8.8
Jaeger Lake	27 Aug	1	5.4	11.4	Kavisilik Lake	18 Jun	1	1.7	11.2
(deep area)					(deep area)	18 Jun	6	2.3	13.7
						13 Jul	1	7.3	12.4
						13 Jul	6	7.1	12.4
						16 Aug	1	14.0	10.0
							9	13.9	10.2
					Kavisilik Lake	29 Jul	-	11.9	11.0
					(outlet)	07 Aug	-	16.3	9.4
					Squiggly Lake	19 Jun	1	0.9	12.8
					(deep area)	19 Jun	7	2.8	10.2
						20 Jul	1	9.7	11.5
						20 Jul	7	9.2	11.5
						19 Aug	1	12.8	9.9
						19 Aug	14	12.8	9.9
					Squiggly Lake	31 Jul	-	10.5	11.4
					(outlet)	08 Aug	-	13.4	10.6

shallow lakes with relatively large wind fetches, such as Pointer Lake, Jaeger Lake and Caribou Lake, wind-driven resuspension of bottom sediments was frequently observed during the ice-free season; these frequent high-wind events substantially reduce water transparency.

5.2 Chemical Characteristics

5.2.1 Dissolved Oxygen

Dissolved oxygen conditions in Kiggavik area lakes, based on measurements taken during the 1979 and 1980 field seasons, are given in Figure 5.1 and Table 5.1. Some depletion of dissolved oxygen levels under ice was evident in 1980, particularly in Sisson's Lake (Figure 5.1). This can be attributed to respiration by the aquatic community during the prolonged season of ice cover, when no mixing or surface re-aeration occurs. In shallower lakes, such as Pointer Lake, the depth of water under ice may be sufficiently low that consumption of dissolved oxygen over the long period of ice cover can result in fish mortality. Evidence of this phenomenon has been reported by site personnel during ice break-up. Under-ice measurements of dissolved oxygen taken in early June 1988 showed concentrations of about 3 mg/L in Pointer Lake (mean depth of 1.5 m), 4 mg/L in Jaeger Lake (mean depth of 1.6 m), and 10 to 12 mg/L in Skinny Lake (mean depth of 3.1 m) and Escarpment Lake (mean depth of 2.2 m), indicating that the amount of oxygen depletion is greater in shallower lakes than in deeper lakes. Welch and Legault (1986) made similar observations to Saqvaqjuac lakes, located east of Baker Lake, and reported that lakes with a mean depth of greater than 3 m have adequate oxygen to support fish over winter. Even deep Saqvaqjuac lakes develop thin anaerobic layers near to the sediment interface in winter.

5.2.2 Dissolved Ions, Nutrients and Trace Elements

Tables 5.2 and 5.3 provide analytical results for water samples collected from selected Kiggavik area lakes in June and July 1989, respectively, while Tables 5.4 to 5.6 provide results for samples taken in 1988 and 1986. Analytical methods used in this study are presented in Appendix 3. All lake water samples collected in these years were subsurface grabs taken from the lake outlets. Two snow-core samples, collected in late winter (early June 1988 and 1989) were also analyzed. The results are listed in Tables 5.2 and 5.4.

TABLE 5.2: WATER QUALITY[1] IN KIGGAVIK AREA SURFACE WATERS, JUNE 1989

	Ore Body Creek	Snow	Skinny Lake	Pointer Lake
pH	5.90/5.85	5.50	6.50	6.35
Conductivity (umhos/cm)	13.7	4.1	11.3	11.0
Alkalinity (as $CaCO_3$)	2.7/2.7	2.7	6.0	4.4
Gran Alkalinity (as $CaCO_3$)	1.0/0.8	0.6	4.5	2.6
Dissolved Inorganic Carbon	0.7	1.5	1.7/1.7	1.2
Dissolved Organic Carbon	2.8	0.9	2.8	2.7
Total Hardness (as $CaCO_3$)	3.5	2.0	5.5	4.0
Total Dissolved Solids	15	5	20	20
Absorbance at 254 nm	0.121	0.042	0.118	0.124
True Colour (Co-Pt)	16	6	14	16
Total Suspended Solids	6	100	4	L 2
Sulphate	1.05	L 0.1	0.65	0.65
Chloride	1.43	0.26	0.42	0.51
Nitrite-N	0.002	0.001	0.002	0.002
Nitrate-N	0.04	L 0.01	0.02	0.01
Ammonia-N	0.033	0.058	0.047	0.050
Total Kjeldahl-N	0.16	0.27	0.22	0.22
Total P	0.004	0.023	0.003	0.005
Soluble Reactive P	L 0.001	L 0.001	L 0.001	L 0.001
Silica (as SiO_2)	0.62/0.62	1.34	0.60	0.34
Fluoride	0.09	0.02	0.11	0.02
Al	0.085	0.46	0.030	0.020
Ag (ug/L)	L 0.1/L 0.1	L 0.1	L 0.1	L 0.1/L 0.1
As (ug/L)	L 1	L 1	L 1	L 1
Ba	0.01	0.03	0.03	0.02
Ca	1.05	0.55	1.45	0.95
Cd (ug/L)	0.4/0.5	0.7	0.8	1.7
Co (ug/L)	2	L 1	1/L 1	L 1
Cr (ug/L)	1	2/2	L 1	L 1
Cu (ug/L)	2.5	2.5/3.0	L 0.5	1.0
Fe	0.25	0.58	0.08	0.07
Hg (ug/L)	L 0.05	L 0.05	L 0.05	L 0.05
K	0.35	0.25	0.40	0.45
Mg	0.20	0.15	0.50	0.35
Mn (ug/L)	18	23/24	16	14
Na	L 0.5	L 0.5	L 0.5	L 0.5
Ni (ug/L)	1	L 1/1	L 1	L 1
Pb (ug/L)	L 0.5	5.5/6.0	1.0	L 0.5
Se (ug/L)	L 0.1	L 0.1	L 0.1	L 0.1
Sr (ug/L)	0.01	L 0.01	L 0.01	L 0.01
Zn (ug/L)	L 5	L 5	L 5	L 5

[1] Concentrations are mg/L unless indicated otherwise.
L = less than.

TABLE 5.3: WATER QUALITY[1] IN KIGGAVIK AREA SURFACE WATERS AND GROUNDWATERS, 04-08 AUGUST 1989

	Field Blank	Pointer Lake		Sissons Lake	Jaeger Lake	Baker Lake			Escarpment Lake	Ridge Lake	Cirque Lake	Skinny Lake
		1	2			1	2	3				
pH	5.45	6.70	6.70	7.00	6.90	7.15	7.15	7.20/7.20	6.70	7.05	6.70	6.95
Conductivity (umhos/cm)	1.33	11.0	11.4	20	15.4	129	129	129	10.2	17.4	8.0	16.1
Alkalinity (as $CaCO_3$)	1.8	5.2	5.2	8.9	6.6	10.5	10.4	10.6/10.8	4.6	8.1	4.4	6.7
Gran Alkalinity (as $CaCO_3$)	0.2	3.0	3.7	7.2	5.1	9.1	8.9	9.3/9.6	3.3	6.9	2.5	5.0
Dissolved Inorganic Carbon	L 0.5	0.9	0.8	1.6	1.0	2.2/2.1	2.1	2.2	0.7	1.5	0.7	1.1
Dissolved Organic Carbon	L 0.2	3.2	2.6	2.3	2.8	2.6	2.6	2.7	2.9	2.7	1.8	2.5
Total Hardness (as $CaCO_3$)	L 0.5	4.0	4.5	8.0	5.5	19.0	19.0	18.5	3.5	7.0	3.3	5.5
Total Dissolved Solids	5	18	14	20	15	75	80	65	2	10	2	60
Absorbance at 254 nm	0.00	0.086	0.084	0.063	0.107	0.073	0.073	0.073	0.115	0.109	0.079	0.088
True Colour (Co-Pt)	L 1	8/8	8	6	9	10	7	7	11	12	10	9
Total Suspended Solids	L 2	L 2	2	L 2	4	L 2	6	4	2	4	4	10
Sulphate	L 0.1	0.30	0.30	0.45	0.30	4.6	4.6	4.8	0.30	0.40	0.20	0.40
Chloride	L 0.01	0.31	0.31	0.43	0.25	28	29	29	0.40	0.39	0.17	0.39
Nitrite-N	L 0.001	0.002	0.002	0.002	0.002	0.003	0.003	0.003	0.002	0.003	0.002	0.002
Nitrate-N	L 0.01	0.01	L 0.01	L 0.01	0.01	0.06	0.02	0.02	0.01	0.01	L 0.01	L 0.01
Ammonia-N	0.025	0.033	0.031	0.026	0.035	0.034	0.034	0.034	0.029	0.030	0.026	0.038
Total Kjeldahl-N	L 0.02	0.21	0.21	0.18	0.24	0.26	0.26	0.23	0.21	0.22	0.16	0.30/0.30
Total P	L 0.001	0.005	0.004	0.001	0.003	0.005	0.009	0.006	0.003	0.003	0.004	0.003
Soluble Reactive P	L 0.001	L 0.001	L 0.001	L 0.001	L 0.001	L 0.001	L 0.001	L 0.001	L 0.001	L 0.001	L 0.001	L 0.001
Silica (as SiO_2)	L 0.02	0.18	0.14	0.14	0.20/0.22	0.52	0.44	0.44	0.56	0.74	0.26	0.24
Fluoride	L 0.01	0.01	L 0.01	L 0.01	0.04	0.05	0.06	0.08	0.03	0.04	0.03	0.15
Al	L 0.005	0.025	0.015	0.005	0.025	0.015	0.015	0.015	0.025	0.035	0.020	0.020
Ag (ug/L)	L 0.1	L 0.1	L 0.1	L 0.1	L 0.1	L 0.1	L 0.1	L 0.1	L 0.1	L 0.1	L 0.1	L 0.1
As (ug/L)	L 1/L 2	L 1	L 1	L 1	L 1	L 1	L 1	L 1	L 1	L 1	L 1/L 2	L 1
Ba	L 0.01	0.03	0.03	0.03	0.04	0.02	0.02	0.02	0.03	0.05	0.03	0.04
Ca	L 0.05	1.10	1.15	2.1	1.55	3.2	3.2	3.2	0.85	1.75	0.85	1.45
Cd (ug/L)	0.2	0.3	0.3	0.7	0.2	L 0.4	0.2	0.3	0.3	0.4	0.3	0.2
Co (ug/L)	L 1	L 1	L 1	L 1	L 1	1	L 1	L 1	L 1/L 1	L 1	1	L 1
Cr (ug/L)	L 1	L 1	L 1	3	L 1	L 1	L 1	L 1	1	5	L 1	L 1
Cu (ug/L)	L 0.5	0.5	0.5	2.0	0.5	L 0.5	L 0.5	L 0.5	L 0.5	L 0.5	L 0.5	L 0.5
Fe	L 0.01	0.03	0.04	0.04/0.04	0.05	0.03	0.03	0.04	0.05	0.10/0.10	0.15	0.07
Hg (ug/L)	L 0.05	L 0.05	L 0.05	L 0.05	0.05	L 0.05	L 0.05	L 0.05	L 0.05	L 0.05	L 0.05	L 0.05
K	L 0.05	0.25	0.25	0.40	0.2	1.10	1.10	1.05	0.25	0.40	0.15	0.25
Mg	L 0.05	0.35	0.35	0.60	0.45	2.7	2.6	2.6	0.30	0.65	0.30	0.50
Mn (ug/L)	L 1	1	2	4	2	8	8	8	2	3	9	3
Na	L 0.5	L 0.5	L 0.5	L 0.5	L 0.5	15.0	14.5	14.5	L 0.5	L 0.5	L 0.5	0.5
Ni (ug/L)	L 1	L 1	L 1	L 1	L 1	L 1	L 1	L 1	L 1	1	L 1	L 1
Pb (ug/L)	L 0.5	L 0.5	0.5	1.0	L 0.5	L 0.5	L 0.5	L 0.5	L 0.5	L 0.5	L 0.5	L 0.5
Se (ug/L)	L 0.1	L 0.1	0.1	L 0.1	0.1	0.1	L 0.1	0.1	L 0.1	L 0.1	L 0.1	L 0.1
Sr (ug/L)	L 0.01	0.01	L 0.01	0.01	0.01	0.03	0.03	0.03	L 0.01	0.01	L 0.01	0.01
Zn (ug/L)	L 5	L 5	L 5	L 5	L 5	L 5	L 5	L 5	L 5	L 5	L 5	L 5

[1] Concentrations are mg/L unless indicated otherwise.

L = less than.

TABLE 5.4: WATER QUALITY[1] IN KIGGAVIK AREA SURFACE WATERS, 02-03 JUNE 1988

	Pointer Lake	Jaeger Lake	Escarpment Lake	Skinny Lake	Snow Sample
pH	6.2	6.4	6.0	6.3	4.3/4.3
Conductivity (umhos/cm)	61	47	20/21	25	5
Alkalinity (pH 3.8) (as $CaCO_3$)	27	25	13	15	6/6
Gran Alkalinity (as $CaCO_3$)	20	18	8	9	2/2
Total Alkalinity (as $CaCO_3$)	20	17	5	7	L 1
Dissolved Inorganic Carbon	6.0	4.5	1.5	2.5	L 0.5
Dissolved Organic Carbon	9.0	8.0/8.0	6.0	4.5	0.5
Colour (Co-Pt)	41/40	37	20	12	L 2
Turbidity (NTU)	1.8	0.57	0.75	0.49	0.71
Sulphate	1.3	0.85	0.60/0.60	0.55	0.35
Chloride	1.6	0.8	0.42/0.42	0.32	0.58
Nitrite-N	L 0.001	0.004	L 0.001	L 0.001	L 0.001
Nitrate-N	0.24	0.13	L 0.01	0.06	0.06
Ammonia-N	0.05	0.12	0.03	0.01	0.07
Total Kjeldahl-N	0.67	0.65/0.66	0.37	0.30	0.18
Total P	0.012	0.009	0.009	0.007	0.005
Soluble Reactive P	L 0.001	0.001	L 0.001	L 0.001	0.001
Silicates	0.60	0.43/0.43	0.97	0.47	0.22
Na	0.96/0.98	0.72/0.76	0.54/0.52	0.50/0.49	0.18/0.20
K	0.825	0.640	0.325	0.325	L 0.05
Mg	2.23	1.72	0.79	0.95	0.06
Ca	7.30	5.75	2.00	2.65	L 0.05
Fe	0.98	0.65	0.040	0.025	0.31
Mn	0.088	0.032	0.0055	0.0026	0.0038
Al	0.050	0.050	0.065	0.030	1.25
Ba	0.16	0.13	0.06	0.06/0.06	L 0.01
Cu (ug/L)	2	1	1	2.5	390
Pb (ug/L)	L 1	L 1	L 1	L 1	1
Ni (ug/L)	3	L 1	L 1	4	20

[1] Concentrations are mg/L unless indicated otherwise.

TABLE 5.5: WATER QUALITY[1] IN KIGGAVIK AREA SURFACE WATERS, 28 JULY 1988

	Pointer Lake	Jaeger Lake	Scotch Lake	Ridge Lake	Escarpment Lake	Skinny Lake	Sissons Lake	Pointer Tributary
pH	6.75	7.15	6.95	7.10/7.10	6.75	7.05	7.25	7.05
Conductivity (umhos/cm)	11	13	20	19	19	14	22	116
Alkalinity (as $CaCO_3$)	4	5	4	7/7	4	5	9	13
Alkalinity (pH 3.8) (as $CaCO_3$)	14	15	14	16/16	12	14	21	23
Dissolved Inorganic Carbon	1.5	1.5	1.5	2.5	1.5	1.5	2.5/2.5	4.0
Dissolved Organic Carbon	2.5	3.0	3.0	3.0	3.5	3.0	2.5/2.5	9.0
Total Hardness (as $CaCO_3$)	4	5	5	8	4	5	8	44
Total Dissolved Solids	L 10	L 10	L 10	L 10	L 10	L 10	L 10	80
Absorbance at 254 nm	0.076	0.089	0.066	0.089	0.116	0.086	0.060	0.404
True Colour (Co-Pt)	10	12	8/8	12	16	11	6	73
Total Suspended Solids	1.5	1.5	2.6	-	-	-	1.1	-
Sulphate	0.30	0.20/0.30	0.30	0.45	0.55	0.45	0.65	2.9
Chloride	0.30	0.34/0.36	0.37	0.57	0.41	0.32	0.50	22
Nitrite-N	0.001	0.001	0.002	0.001	0.001	0.002	0.001	0.002
Nitrate-N	L 0.02	L 0.02	L 0.02	L 0.02	0.02	L 0.02	L 0.02	L 0.02
Ammonia-N	0.02	0.02	0.03/0.03	0.03	0.03	0.03	0.02	0.01
Total Kjeldahl-N	0.17/0.18	0.22	0.22	0.20	0.21	0.18	0.18	0.44
Total P	0.003	0.004	0.004	0.005	0.004	0.004	0.004	0.005
Soluble Reactive P	L 0.001	L 0.001	L 0.001	0.005	L 0.001	L 0.001	L 0.001	L 0.001
Silica (As SiO_2)	0.10	0.08	0.16	0.58	0.58	0.24	0.16	2.5
Fluoride	0.06	0.06/0.06	0.06	0.07	0.06	0.18	0.11	0.32/0.35
Al	0.035	0.035	0.020	0.055	0.045	0.055	0.020	0.138
Ag (ug/L)	L 0.1	L 0.1	L 0.1	L 0.1	L 0.1	L 0.1	L 0.1	L 0.1
As (ug/L)	L 1	L 1	L 1	L 1	L 1	L 1/L 2	L 1	L 1
Ba	0.02	0.03/0.04	0.04	0.05	0.03	0.03	0.03	0.14
Ca	1.10	1.30/1.30	1.20	1.95	0.95	1.40	2.2	13.3
Cd (ug/L)	0.2	0.2	0.3	0.3	0.4	0.5	0.3	0.3/0.4
Co (ug/L)	1/1	1	L 1	L 1	1	L 1	1	1
Cr (ug/L)	1	L 1	L 1	2	4/4	12/13	L 1	L 1/1
Cu (ug/L)	0.5	0.5	0.5	0.5	0.5	1.5	0.5/0.5	4.5
Fe	0.06	0.04	0.08	0.08	0.06	0.08	0.06	2.5/2.5
Hg (ug/L)	L 0.05	L 0.05	L 0.05	L 0.05	L 0.05	L 0.05	L 0.05	L 0.05
K	0.20	0.15/0.15	0.25	0.35	0.15	0.25	0.30	1.25
Mg	0.40	0.45/0.45	0.45	0.75	0.40	0.50	0.70	2.6
Mn (ug/L)	1	1	1	2	3	3	4	113
Na	L 0.5	L 0.5	L 0.5	L 0.5	L 0.5	L 0.5	L 0.5	1.5
Ni (ug/L)	L 1	L 1	L 1	2	1	1	L 1	1/2
Pb (ug/L)	L 0.5	L 0.5	L 0.5	L 0.5	0.5	L 0.5	1.0	1.0
Se (ug/L)	L 0.1	L 0.1	L 0.1	L 0.1	L 0.1	L 0.1	L 0.1	L 0.1
Zn (ug/L)	L 5	L 5	L 5	L 5	L 5	L 5	L 5	L 5
Chlorophyll a (ug/L)	1.10	1.58	0.64	-	-	-	1.48	-

[1] Concentrations are mg/L unless indicated otherwise.

TABLE 5.6: DETAILED WATER QUALITY[1] DATA IN KIGGAVIK AREA LAKES, JULY 1986

	Scotch Lake	Drum Lake	Pointer Lake	J. Sisson's Lake	Skinny Lake	Drill Site Drainage	Drill Site Control
pH	5.9	5.6	5.8	6.3	6.1	6.1	6.0
Alkalinity (as $CaCO_3$)	3	2	3	7	3	6	5
Total Dissolved Solids	13	31/37	28	33	6	117	34
Conductivity (umhos)	14	18	14	25	16	195	36
Total Organic Carbon	4.5	8.0	4.5	4.5	4.0	7.5	6.0
Total Kjeldahl N	0.20	0.45	0.36	0.22	0.38	0.46	0.25
Total P	L 0.001	0.002	L 0.001	L 0.001	0.002	0.01	0.006
Orthophosphate P	L 0.1	L 0.1	L 0.1	L 0.1	L 0.1	L 0.1	L 0.1
Cl^-	0.29	0.17	0.29	0.50	0.25	46	0.37
Nitrite-N	L 0.1	L 0.1	L 0.1	L 0.1	L 0.1	L 0.1	L 0.1
Nitrate-N	L 0.003	L 0.003	0.032	0.003	L 0.003	0.003	0.36
F^-	0.048	0.048	0.046	0.06	0.126	0.30	0.50
SO_4^{2-}	0.42	0.28	0.26	0.70	0.40	41	6.5
Be	L 0.005	L 0.005	L 0.005	L 0.005	L 0.005	L 0.005	L 0.005
Mo	L 0.01	L 0.01	L 0.01	L 0.01	L 0.01	0.02	0.02
Ca	1.30	2.1	1.45	3.0	1.45	25	3.7
V	L 0.005	L 0.005	L 0.005	L 0.005	L 0.005	0.005	L 0.005
Al	0.02	0.10	0.02	L 0.02	0.04	1.52	0.42
Mg	0.46	0.62	0.44	0.84	0.54	3.9	1.34
Ba	0.055	0.050	0.035	0.040	0.035	0.23	0.045
K	0.15	0.20	0.10	0.35	0.15	3.2	0.45
Sr	0.01	0.02	0.01	0.02	0.01	0.33	0.03
Na	L 0.5	L 0.5	L 0.5	L 0.5	L 0.5	2.5	0.5
Zn	L 0.01	0.01	L 0.01	L 0.01	L 0.01	0.01	L 0.01
Cd	L 0.01	L 0.01	L 0.01	L 0.01	L 0.01	L 0.01	L 0.01
Mn	L 0.01	L 0.01	L 0.01	0.02	L 0.01	0.09	L 0.01
Co	L 0.01	L 0.01	L 0.01	L 0.01	L 0.01	L 0.01	L 0.01
Cu	0.005	L 0.005	L 0.005	L 0.005	L 0.005	0.01	0.015
Fe	0.09	0.11	0.05	0.04	0.08	1.55	0.19
Pb	L 0.05	L 0.05	L 0.05	L 0.05	L 0.05	L 0.05	L 0.05
Cr	L 0.01	L 0.01	L 0.01	L 0.01	L 0.01	L 0.01	L 0.01
Ni	L 0.01	L 0.01	L 0.01	L 0.01	L 0.01	L 0.01	L 0.01
As (ug/L)	L 1	L 1	L 1	L 1	-	-	-
Hg (ug/L)	L 0.02	L 0.02	L 0.02	0.02	-	-	-
Se (ug/L)	L 0.5	L 0.5	L 0.5	L 0.5	-	-	-

	Ridge Lake	Cirque Lake	Crash Lake	Caribou Lake	Felsenmeer Lake	Escarpment Lake	Meadow Lake	Sik-Sik Lake
pH	6.2	5.9	6.2	6.4	6.1	5.8	6.4	6.2
Alkalinity (as $CaCO_3$)	5	2	7	5	3	2	8	12
Total Dissolved Solids	7	12/14	24/27	33	34	9	15	29
Conductivity (umhos)	18	10	22	20	14	13	25	35
Total Organic Carbon	3.5	4.0	5.0	4.5	4.0	5.5	8.5	8.0
Total Kjeldahl N	0.31	0.18	0.44	0.33	0.23	0.37	0.47	0.44
Total P	0.003	L 0.001	0.007	0.004	L 0.001	0.004	LE 0.001	L 0.001
Orthophosphate P	L 0.1	L 0.1	L 0.1	L 0.1	L 0.1	L 0.1	L 0.1	L 0.1
Cl^-	0.35	0.27	0.28	0.41	0.25	0.25	0.34	0.66
Nitrite-N	L 0.1	L 0.1	L 0.1	L 0.1	L 0.1	L 0.1	L 0.1	L 0.1
Nitrate-N	L 0.003	L 0.003	L 0.003	L 0.003	LE 0.003	0.003	L 0.003	L 0.003
F^-	0.046	0.044	0.048	0.060	0.042	0.028	0.068	0.100
SO_4^{2-}	0.44	0.24	0.28	0.32	0.038	0.34	0.28	0.30
Be	L 0.005	L 0.005	L 0.005	L 0.005	L 0.005	L 0.005	L 0.005	L 0.005
Mo	L 0.01	L 0.01	L 0.01	L 0.01	L 0.01	L 0.01	L 0.01	L 0.01
Ca	1.85	0.85	2.2	1.90	1.40	1.05	2.8	5.0
V	L 0.005	L 0.005	L 0.005	L 0.005	L 0.005	L 0.005	L 0.005	L 0.005
Al	0.04	0.02	0.04	0.02	L 0.02	0.06	L 0.08	0.04
Mg	0.68	0.34	0.80	0.58	0.54	0.4	1.14	1.52
Ba	0.050	0.03	0.050	0.025	0.025	0.030	0.075	0.065
K	0.25	0.10	0.20	0.30	0.15	0.15	0.40	0.40
Sr	0.02	L 0.01	0.02	0.01	L 0.01	L 0.01	0.02	0.03
Na	L 0.5	L 0.5	L 0.5	L 0.5	L 0.5	L 0.5	0.5	L 0.5
Zn	L 0.01	L 0.01	L 0.01	L 0.01	L 0.01	L 0.01	L 0.01	L 0.01
Cd	L 0.01	L 0.01	L 0.01	L 0.01	L 0.01	L 0.01	L 0.01	L 0.01
Mn	L 0.01	0.01	L 0.01	L 0.01	L 0.01	L 0.01	L 0.01	L 0.01
Co	L 0.01	L 0.01	L 0.01	L 0.01	L 0.01	L 0.01	L 0.01	L 0.01
Cu	L 0.005	L 0.005	L 0.005	L 0.005	L 0.005	L 0.005	0.005	L 0.005
Fe	0.07	0.10	0.11	0.06	0.16	0.05	0.27	0.22
Pb	L 0.05	L 0.05	L 0.05	L 0.05	L 0.05	L 0.05	L 0.05	L 0.05
Cr	L 0.01	L 0.01	L 0.01	L 0.01	L 0.01	L 0.01	L 0.01	L 0.01
Ni	L 0.01	L 0.01	L 0.01	L 0.01	L 0.01	L 0.01	L 0.01	L 0.01
As (ug/L)	L 1	-	-	L 1	L 1	L 1	-	-
Hg (ug/L)	L 0.02	-	-	0.06	L 0.02	L 0.02	-	-
Se (ug/L)	L 0.5	-	-	L 0.5	L 0.5	L 0.5	-	-

[1] All results except pH in mg/L unless indicated otherwise.

L - less than

LE - less than or equal to

Concentrations of nutrient elements, phosphorus and nitrogen are low in Kiggavik area lakes, and fall within the range of concentrations expected in oligotrophic lakes. This is consistent with the low mid-summer chlorophyll a concentrations of 0.6 to 1.6 ug/L (Table 5.5), which is at the low end of the chlorophyll concentration range reported for dilute Saqvaqjuac lakes (Welch and Legault, 1986).

Some winter-summer differences are apparent in Kiggavik area lake water quality, based on comparison of Tables 5.4 (sampled under ice in early June 1988) and 5.5 (open water conditions in July 1988). For conservative ions such as Na^+, Mg^{2+}, K^+ and Cl^-, lower concentrations in open water can be attributed to the effects of dilution by snow melt and "freeze-out", or cryoconcentration, which tends to concentrate these elements in the unfrozen volume of the lake, as reported for Saqvaqjuac (Welch and Legault, 1986). Similar differences in sulphate concentrations between winter and summer periods suggest that substantial sulphate reduction did not occur even in shallow lakes such as Pointer. Freeze-out may also account for some of the increase in nutrient concentrations under ice, although phosphorus and nitrogen freeze-out is apparently much less efficient than is freeze-out of other ions (Welch and Legault, 1986). Nutrients may also be regenerated during organic matter decomposition processes occurring under the ice.

Chemical analysis of the snow core sample showed that the snow is acidic (pH 4.3 to 5.5; Tables 5.2 and 5.4) and dilute relative to lake water in conductivity, alkalinity, organic carbon, colour, calcium, magnesium, potassium and barium. Major ion concentrations tend to be slightly lower in snow than in lake water. Despite the relatively dilute nature of snowmelt, lake water quality measured during the peak of the spring freshet in June 1989 (Table 5.2) did not differ markedly from lake water quality during the summer base flow period in August 1989 (Table 5.3). Concentrations of some heavy metals in snow were much greater than in lake waters (Tables 5.2 and 5.4); substantial fractions of these metals may have occurred in association with the high levels of suspended solids found in the snow (Table 5.2). Concentrations of major ions in Kiggavik snow are similar to those reported at Saqvaqjuac for SO_4, Cl, K, Mg and Na, but were much lower for Ca. Welch and Legault (1986) noted that Ca concentrations in Saqvaqjuac snow were higher than averages reported in other studies.

The fact that lake chemistry is less acidic than the snow suggests that these lakes have considerable buffering capacity. This is particularly relevant with respect to controlling optimal conditions for aquatic life.

A small stream draining towards Pointer Lake draining a mineral exploration area was sampled in 1986, 1988 and 1989. Samples of this water showed high concentrations of total dissolved solids, chloride, sulphate, calcium, sodium, potassium and several trace metals (iron, manganese, aluminum, barium) relative to other local surface waters (Tables 5.5 and 5.6). Concentrations were higher in 1986 when active drilling was in progress than in 1988 when no drilling was carried out at the site. A major source of ions is probably the salt used as an antifreeze in the drilling operation. None of the parameters occurring at high concentrations in drainage from the drilling sites were found in Pointer Lake at concentrations above the background levels typical of other local lakes, indicating that this source is insignificant in the natural cycle of these elements in Pointer Lake. Water quality in this stream during the 1989 freshet was similar to water quality in the lakes sampled during the same period, reflecting the longer recovery period after the drilling program, as well as the high degree of dilution during the freshet (Table 5.2).

Baker Lake was sampled for the first time in the Urangesellschaft environmental program in August 1989. Three samples (triplicates) were collected from the lake front at Baker Lake (in front of the Urangesellschaft office), at a water depth of about 1 m. This water was relatively high in conductivity (about ten times the levels measured at the Kiggavik site), and high in major ions, particularly sodium and chloride (30 to 100 times the levels measured at the Kiggavik site; Table 5.3). The differences in water quality between Baker Lake and the Kiggavik area lakes can be attributed to differences in runoff water quality, and to the marine influence in Baker Lake (some intrusion of seawater occurs into the lake through Chesterfield Inlet) and possibly local runoff from the Baker Lake town site.

An analytical summary of Kiggavik area surface water quality data for all survey years (1979, 1980, 1986, 1988 and 1989) is provided in Table 5.7. Also included is a summary of Baker Lake chemistry from 1974 to 1982, collected by the Water Survey of Canada. This table also provides comparative data on Saqvaqjuac lakes east of Baker Lake, the Experimental Lakes Area (ELA) in a remote Precambrian Shield region of northwestern

TABLE 5.7: BACKGROUND SURFACE WATER QUALITY IN KIGGAVIK AREA LAKES IN COMPARISON WITH WATER QUALITY IN OTHER AREAS AND REGULATORY LIMITS FOR SURFACE WATER QUALITY

	1988 Background Range[1]	1986 Background Range[1]	1980 Background Range[2]	1979 Background Range[3]	1974-1982 Baker Lake[4]	Saqvaqjuac Background Range (approx)[5]	ELA Background Average[6]	Global Average Rivers[7]	Drinking Water HWC[8]
pH	6.0-7.25	5.6-6.4	4.1-6.5	6.1-8.0	5.6-7.2	5.8-7.3	5.6-6.7		6.5-8.5
Alkalinity (as $CaCO_3$)	4-27	2-12		0.05-38	3-12				
Total Dissolved Solids	L 10	5-30			17-1,040			33	500
Conductivity (umhos/cm)	11-61	10-36	0-31		32-2,180	24-105	19		
Total Organic Carbon	-	3.5-8.5			-				
Total Kjeldahl N	0.17-0.67	0.18-0.45			L 0.5-0.41				
Total P	0.003-0.012	L 0.001-0.007			L 0.003-0.033			0.02	
Orthophosphate P	L 0.001-0.005	L 0.1			-		L 0.001		
Cl^-	0.30-1.6	0.17-0.66			3.2-580	L 1-12	1.4	8	250
Nitrite-N	L 0.001-0.004	L 0.1			-				1
Nitrate-N	L 0.01-0.24	L 0.003-0.32			-		L 0.02		10
F^-	0.06-0.18	0.028-0.126			-				1.5
SO_4^{2-}	0.20-0.65	0.038-0.7			1.7-68	1-20	3		500
Be	-	L 0.005-L 0.005			-			L 0.0001	
Mo	-	L 0.01-0.02			-			0.001	
Ca	2.0-7.3	0.85-5.0			1.8-24	1-40	1.6		
V	-	L 0.005			L 0.001-0.003			0.001	
Al	0.02-0.065	L 0.02-0.42			L 0.1-0.1			0.4	
Mg	0.40-2.23	0.34-1.52			-	0.1-4	0.9	4.1	
Ba	0.02-1.6	0.025-0.075			L 0.1-0.1			0.01	1
K	0.15-0.825	0.10-0.45			0.5-12	L 0.1-2	0.4		
Sr	-	L 0.01-0.03			-			0.050	
Na	L 0.5-0.98	L 0.5-0.5			-	L 1-8	0.9	9	
Zn	L 0.005	L 0.01-0.01	0.0016-0.0046	0.07-8.53**	L 0.001-0.006			0.010	5
Cd	0.0002-0.0005	L 0.01	L 0.0005-0.002	L 0.0005-0.0005	L 0.001-0.001				0.005
Mn	0.001-0.088	L 0.01-0.024			L 0.01-0.012			0.005	0.05
Co	L 0.001-0.001	L 0.01			L 0.001-0.001			0.0002	
Cu	0.0005-0.0025	L 0.005-0.01	0.0008-0.002	0.11-14.8**	L 0.001-0.001			L 0.005	1
Fe	0.04-0.98	0.04-0.27			L 0.005-0.005		0.05	0.67	0.3
Pb	L 0.0005-0.001	L 0.05	0.002		L 0.004-0.005			0.003	0.05
Cr	L 0.001-0.013	L 0.01	L 0.005	0.011-0.84	L 0.01-0.01				0.05
Ni	L 0.001-0.004	L 0.01			L 0.005-0.005			0.0003	
As (ug/L)	L 1	L 1	L 0.2	L 0.5	-			1	50
Hg (ug/L)	L 0.05	L 0.02-0.06	L 0.01-0.05	L 10	-			0.07	1
Se (ug/L)	L 0.1	L 0.5		L 0.5	-			0.2	10

Source:

1 This study
2 Urangesellschaft (1981)
3 Urangesellschaft (1979)
4 Water Survey of Canada
5 Welch and Legault (1986)
6 Armstrong and Schindler (1971)
7 Riley and Chester (1971)
8 Health and Welfare Canada (1979)
9 CCREM (1987)

* Water quality objectives for soft-water environments.
** Sample contamination by Cu and Zn strongly suspected.
Notes: Background ranges exclude results for snow samples and the Pointer Lake Tributary draining a mineralized area. Concentrations are mg/L unless indicated otherwise.

1989 Background Range[1]	Protection of Aquatic Life CCREM[9]
6.35-7.05	6.5-9.0
4.4-8.9	
2-60	
8-20	
-	
0.16-0.30	
0.001-0.005	
L 0.001	
0.17-0.51	
0.002-0.003	0.06
L 0.01-0.02	
L 0.01-0.15	
0.20-0.65	
-	
-	
0.85-2.1	
-	
0.005-0.035	
0.30-0.65	
0.02-0.05	
0.15-0.45	
L 0.01-0.01	
L 0.5-0.5	
L 0.005	0.03
0.0002-0.0017	0.0002
0.0001-0.0016	
L 0.001-0.001	
L 0.0005-0.002	0.002
L 0.03-0.15	0.3
L 0.0005-0.001	0.001
L 0.001-0.005	0.002
L 0.001-0.001	0.025
L 1	50
L 0.05-0.05	0.1
L 0.1-0.1	1

Ontario, and global average values for rivers. Regulatory criteria for drinking water and for protection of aquatic life are also given.

In general, Kiggavik area lakes tend to be dilute in comparision with the global average for river water and, for many parameters, tend to be more dilute than Saqvaqjuac and ELA lakes. In general, lakes situated on watersheds of granitic surficial geology tend to be dilute, softwater lakes. This is true of the lakes covering the vast area of the Canadian Shield. The inland location of the Kiggavik development area isolates its watersheds from the effects of marine aerosols that tend to introduce solutes to Saqvaqjuac area lakes. Also, permafrost in the Arctic may decrease the effects of weathering of soils and rock surfaces by decreasing the surface area available for weathering (Welch and Legault, 1986). These factors influence surface water quality throughout the Keewatin District.

All parameters measured in water collected from Kiggavik area lakes were below maximum acceptable concentrations set by Health and Welfare Canada for drinking water supplies. Three metals - copper, cadmium and chromium - occurred in some samples at concentrations above the CCREM (1987) water quality guidelines for the protection of aquatic life; however, all concentrations of these metals, with the exception of some apparently contaminated samples collected in 1979, fall within ranges identified as background for unpolluted Canadian surface waters by CCREM (1987).

Samples of groundwater were collected from several areas to provide baseline data on groundwater chemistry (Table 5.8). Samples were collected from two seeps in the active zone - one on the "Main Zone" ore body and at a reference site near Sauna Lake. These samples were small-volume subsamples decanted from 180-L samples collected for radionuclide analysis. During geotechnical studies for the erection of structures at the Kiggavik site, an opportunity arose to collect samples of permafrost from depths several metres below the ground surface. These samples were thawed, filtered and analyzed for trace metals and major ions and cations. As shown in Table 5.8, the composition of groundwater varies substantially around the Kiggavik site and, for the most part, groundwaters have higher concentrations of major ions than do surface waters. The Main Zone ore body contained relatively high concentrations of manganese, lead and cobalt relative to other samples, possibly reflecting higher concentrations of these metals in the mineralized matrix.

TABLE 5.8: CHEMISTRY OF GROUNDWATER FROM THE ACTIVE ZONE AND FROM PERMAFROST IN THE KIGGAVIK AREA

	Concentrations mg/L unless indicated otherwise									
	ACTIVE ZONE (August 1989)			PERMAFROST ZONE (August 1988)						
	Main Zone 1	Main Zone 2	Sauna Lake	Mill Site 1[1]	Mill Site 2[1]	Ridge Lake Area[1]	Cirque Lake Area[1]	Skinny Lake Area[2]	Drumlin[2]	Pointer Lake Area[2]
pH	6.70	6.70	7.30	7.20	7.90	7.5	6.75/6.86	6.60	7.60	7.95
Conductivity (umhos/cm)	173	172	44	130	1,210	105/105	99	30	74	441
Alkalinity (as $CaCO_3$)	10.9	11.1	15.7	57	330	41	41	11	26	230
Gran Alkalinity (as $CaCO_3$)	10.0	9.4	14.5	-	-	-	-	-	-	-
Alkalinity, pH 3.8 (as $CaCO_3$)	-	-	-	72	350	52	53	21	37	240
Dissolved Inorganic Carbon	3.1	2.9	3.3	13	78	11	11	3	5	55
Dissolved Organic Carbon	11.9	12.2	6.6	-	-	-	-	-	-	-
Total Hardness (as $CaCO_3$)	67	67	22	-	-	-	-	-	-	-
Total Dissolved Solids	160	160	60	140	420	85	90	20	45	210/240
Absorbance at 254 nm	0.667	0.683	0.490	-	-	-	-	-	-	-
True Colour (Co-Pt)	99	98	90	-	-	-	-	-	-	-
Total Suspended Solids	30	32	16	-	-	-	-	-	-	-
Sulphate	42	42	4.3	3.8	34/32	4.0	2.6/2.6	0.10	4.7	8.2
Chloride	15.7	15.2	0.37	3.0	137	3.8	2.0/2.0	0.40	0.90	2.1
Nitrite-N	0.018	0.015	0.018	-	-	-	-	-	-	-
Nitrate-N	L 0.01	L 0.01	0.08	-	-	-	-	-	-	-
Ammonia-N	0.119	0.119	0.067	-	-	-	-	-	-	-
Total Kjeldahl-N	0.87	0.91/0.93	0.38	-	-	-	-	-	-	-
Total P	0.063	0.061	0.039	-	-	-	-	-	-	-
Soluble, Reactive P	0.030	0.028	0.022	-	-	-	-	-	-	-
Silica (as SiO_2)	8.7	8.9	7.1	16.1	11.3	10.7	10.4/10.5	5.3	19.5	8.1
Fluoride	0.27	0.28	0.19	-	-	-	-	-	-	-
Al	0.73	0.75	0.82	1.06	1.18	0.38	0.56	0.02	3.1/3.1	0.08
Ag (ug/L)	L 0.1/L 0.1	L 0.1	L 0.1	L 0.1	L 0.1/L 0.1	L 0.1	L 0.1	0.2	L 0.1	0.2
As (ug/L)	L 1	L 1	L 1	1	7	1	8	1	2	L 2/L 5
Ba	0.12	0.12	0.07	0.43	1.24	0.27	0.29	0.12	0.32/0.32	0.37
Ca	17.1	17.1	5.7	12.6	19.2	9.9	11.8	2.6	8.3/8.5	63
Cd (ug/L)	0.4	0.6	0.2	0.1	L 0.1/L 0.1	L 0.1	L 0.1	0.2	0.1	0.1
Co (ug/L)	29	27	1	1	1	L 1	23/22	1/1	2	1
Cr (ug/L)	1/2	2	2	1	1/1	1	2	L 1	1	1
Cu (ug/L)	14.5/15.0	14.5	8.0	10	5.5	6.0	12.5	5.5	25/30	2.0/2.0
Fe	0.52	0.48	0.86/0.87	0.66	0.74	0.28	0.90	0.04	1.98	L 0.02
Hg	L 0.05	0.05	L 0.05	L 0.1	L 0.1	L 0.1	L 0.1	L 0.1	L 0.1	L 0.1/L 0.2
K	2.5	2.5	1.15	2.2	18.6	1.55	1.85	0.15	1.65/1.65	3.8
Mg (ug/L)	5.9	5.9	1.8	6.0	8.9	4.5	3.7	1.0	3.4/3.4	17.5
Mn	280	290	18	0.08	0.44	0.02	0.83	0.02	0.1	0.03
Na	2.0	2.0	1.5	2.0	56	1.5	1.0	0.5	2.5/2.5	5.0
Ni	8/8	8	2	6	7	4	7/6	4	8	1
Pb	13/13	12	1	1	1	1/L 1	2	L 2	1	2
Se	3.5	2.1	0.1	L 1	L 1	L 1	L 1	L 1	L 1/L 2	L 1
Sr	0.15	0.15	0.05	-	-	-	-	-	-	-
Zn	5	5	L 5	5	L 5	L 5	10	L 5	30	L 5

L = less than.
[1] Groundwater from bedrock.
[2] Groundwater from till.

TABLE 5.9: CONCENTRATIONS OF RADIONUCLIDES IN SURFACE WATER SAMPLES COLLECTED IN KIGGAVIK AREA LAKES

Water Body	U (ug/L)	Th-230 (Bq/L)	Ra-226 (Bq/L)	Pb-210 (Bq/L)	Po-210 (Bq/L)	Th-232 (Bq/L)	Th-228 (Bq/L)
04-08 August 1989							
Cirque Lake	L 0.5	-	0.0012	-	-	-	-
Jaeger Lake	L 0.5	-	0.00096	-	-	-	-
Ridge Lake	L 0.5	-	0.0008	-	-	-	-
Sissons Lake - preconcentrated	0.08	0.00026	0.0004	-	0.0026	0.00002	0.0002
Sissons Lake - whole-water	L 0.5	-	-	-	-	-	-
Pointer Lake - preconcentrated	0.15	0.002	0.0022	-	0.0029	L 0.00005	0.0004
Pointer Lake - whole-water	L 0.5	-	-	-	-	-	-
Baker Lake - preconcentrated	0.37	0.0008	0.0016	-	0.0028	0.0001	0.0006
Baker Lake - whole-water	L 0.5	-	-	-	-	-	-
05-10 June 1989							
Skinny Lake	L 0.5						
Orebody Drainage	4.6						
Snow	L 0.5						
24-26 July 1988							
Scotch Lake	0.38	0.000087	L 0.0014			0.000059	0.00059
Jaeger Lake	8.6	0.00077	L 0.0016			0.00018	0.0012
Pointer Lake	0.71	0.00037	L 0.0015			0.00037	0.0015
Sissons Lake	1.1	0.00025	L 0.0015			0.00012	0.0012
Pointer Tributary[1]	11	0.070	-			0.0038	0.0084
Snowmelt	0.56	0.054	-			0.0019	0.0089
31 May to 01 June 1988							
Pointer Lake	1.0	L 0.005	L 0.005	L 0.2	L 0.005	L 0.005	-
Escarpment Lake	1.0	L 0.005	L 0.005	L 0.2	L 0.005	L 0.005	-
Skinny Lake	0.5	L 0.005	L 0.005	L 0.2	L 0.005	L 0.005	-
Jaeger Lake	1.5	L 0.005	L 0.005	L 0.2	0.008±0.005	L 0.005	-
Snow Sample	1.0	L 0.005	0.007±0.005	L 0.2	0.026±0.006	L 0.005	-
25-30 July 1986							
Pointer Lake	L 0.2	L 0.005	L 0.5	L 0.1	0.037	L 0.001	-
D-S-S[2]	L 0.1	L 0.002	L 0.01	L 0.03	L 0.03	-	-
M-E-F[2]	L 0.1	L 0.002	L 0.01	L 0.03	L 0.03	-	-
R-C[2]	L 0.1	L 0.002	L 0.01	L 0.03	L 0.03	-	-
C-C[2]	L 0.1	L 0.002	L 0.01	L 0.03	L 0.03	-	-
Skinny Lake	L 0.1	L 0.002	L 0.02	L 0.03	L 0.03	-	-
Sissons Lake	L 0.1	L 0.002	L 0.02	L 0.03	L 0.03	-	-
Pointer Tributary[3]:							
o upstream	0.14	0.20	L 0.02	L 0.03	L 0.03	-	-
o downstream	10.8	0.45	0.88	0.48	0.47	-	-
August 1980							
Scotch Lake	L 0.5	L 0.01	L 0.007	L 0.02	-	L 0.01	L 0.01
Jaeger Lake	0.2	L 0.01	0.13	L 0.02	-	L 0.01	L 0.02
Pointer Lake	0.2	L 0.01	0.13	L 0.02	-	L 0.01	L 0.02
Sissons Lake Inlet	L 0.5	L 0.01	0.03	0.026	-	L 0.01	L 0.01
Sissons Lake Outlet	L 0.5	L 0.01	0.03	L 0.02	-	L 0.01	L 0.01
Kavisilik Lake	L 0.5	L 0.01	0.007	0.033	-	L 0.01	L 0.01
Crash Lake	L 0.5	L 0.01	L 0.007	L 0.02	-	L 0.01/L 0.01	L 0.01
Squiggly	L 0.5	0.02	L 0.007	L 0.02	-	L 0.01/L 0.01	L 0.01
August 1979							
Lin Lake	L 0.5	-	0.015	L 0.04	-	0.03	-
Scotch Lake	L 0.5	-	0.037	0.07	-	L 0.004	-
Jaeger Lake	L 0.5	-	0.026	L 0.04	-	0.004	-
Crash Lake	L 0.5	-	0.037	L 0.04	-	L 0.004	-
Unnamed Lake[4]	L 0.5	-	0.019	0.04	-	L 0.004	-
Sik-Sik	L 0.5	-	L 0.004	L 0.04	-	0.006	-
Sissons Lake Inlet	L 0.5	-	L 0.004	0.04	-	L 0.004	-
Sissons Lake Outlet	L 0.5	-	0.011	L 0.04	-	L 0.004	-

1 Pointer tributary draining mineralized area.

2 Composite samples: D-S-S = Drum, Scotch, Sik-Sik; M-E-F = Meadow, Escarpment, Felsenmeer; R-C = Ridge, Cirque; C-C = Crash, Caribou.

3 Pointer tributary, upstream and downstream of mineralized area.

4 Unnamed Lake draining into north end of Caribou Lake.

Whole-water and preconcentrated sampling is discussed in Appendix 3.

5.2.3 Radionuclides

Levels of radionuclides in surface waters from the Kiggavik area are listed in Table 5.9 for individual unfiltered samples collected in 1979, 1980, 1986, 1988 and 1989. A summary of data is provided by year and by radionuclide in Table 5.10, along with comparative values for Saqvaqjuac and global averages. Criteria set by regulatory agencies for drinking water quality, protection of aquatic biota and mining effluents are also listed in Table 5.10.

Prior to 1988, levels of most radionuclides were at or below analytical detection limits for unconcentrated water samples. Detectable levels for most radionuclides are reported for 1988 and 1989, owing to the analysis of samples pre-concentrated from large water volumes in the field (see Appendix 3). Radium-226, which could be analyzed only by Rn-emanation due to the Ba-133 tracer and stable Ba carrier used in sample pre-concentration, was undetected in 1988. This lack of detection can, in part, be attributed to the relatively high detection of the Rn-emanation method (0.02 Bq per sample of precipitate; see Section A5 - Appendix 3).

In general, total uranium concentrations were higher and Th-232 levels lower in Kiggavik area surface waters than in Saqvaqjuac surface waters. With the exception of an unusually high uranium value for Jaeger Lake in 1988 (8.6 ug/L), uranium concentrations found in 1988 and 1989 were close to those reported in earlier years at Kiggavik. Other radionuclides in the U-238 decay chain occurred at levels that are generally similar to those found at Saqvaqjuac, although differences in detection limits for some radionuclides preclude close comparisons.

The data on radionuclide levels in the Pointer Lake tributary draining an area of surface mineralization are noteworthy. This stream showed higher concentrations of most radionuclides analyzed than found in any lake samples. The 1988 sample, collected downstream of the mineralized area, was collected at a time when no exploratory drilling was being carried out in the watershed. The samples collected in 1986 were taken both upstream and downstream of the ore bodies. The conclusions that can be drawn from these data are that radionuclides are mobilized from the mineralized area to the watershed.

TABLE 5.10: BACKGROUND RANGES OF RADIONUCLIDE CONCENTRATIONS AND ACTIVITIES IN KIGGAVIK AREA SURFACE WATERS, COMPARATIVE DATA FROM OTHER LOCATIONS, AND REGULATORY OBJECTIVES FOR WATER QUALITY

	1989 Background Range[1]	1988 Background Range[1]	1986 Background Range[1]	1980 Background Range[2]	1979 Background Range[3]	Saqvaqjuac Background Range[4]	Global Average Rivers[5]	Mine Effluent Maximum[6]	Drinking Water HWC[7]	Protection of Aquatic Life Env. Canada[8]
U (ug/L)	0.08-0.37	0.38-8.6	L 0.1-0.14	L 0.5-0.8	L 0.5	0.022-0.081	0.04		100	300
Th-230 (Bq/L)	0.00026-0.002	0.000087-0.00077	L 0.002-0.002	L 0.01-L 0.02		L 0.00004-0.00017				
Ra-226 (Bq/L)	0.00096-0.0016	L 0.0014-L 0.0016	L 0.01-L 0.02	0.007-0.13	L 0.004-0.037	L 0.0001-0.0011		0.37	1.0	
Pb-210 (Bq/L)	-	-	L 0.03	L 0.02-0.033	L 0.04-0.07	0.00078-0.0106				
Po-210 (Bq/L)	0.0026-0.0029	L 0.005-0.008	L 0.03			0.00129-0.0043				
Th-232 (Bq/L)	0.00002-0.0001	0.000059-0.00012	L 0.001	L 0.01	L 0.004-0.03	0.005-0.032	0.0004			
Th-228 (Bq/L)	0.0002-0.0006	0.00059-0.0015	-	L 0.01-L 0.02	-	-	-			

Sources:

[1] This study - note: 1988 data based on July samples for all parameters except Po-210.

[2] Urangesellschaft (1981)

[3] Urangesellschaft (1979)

[4] Brunskill et al. (1986)

[5] Riley and Chester (1971)

[6] Environment Canada (1977)

[7] Health and Welfare Canada (1988)

[8] Environment Canada (1987)

Note: 1986 and 1988 background excluding Pointer Lake tributaries draining mineralized areas.

A sample of groundwater collected from the "Main Zone" ore body in August 1989 showed very high concentrations of U-238 decay chain radionuclides relative to a background control groundwater sample collected from a seep at the toe of the cliff bordering the north side of Sauna Lake, and relative to surface water samples collected in the Kiggavik area (Table 5.11). Because there were relatively high concentrations of suspended solids (30 to 32 mg/L; Table 5.3), it was felt that radionuclides associated with the suspended particles might tend to increase the total radionuclide concentrations measured in the unfiltered sample. A sample of the fine silty-clay deposits, found at the bottom of each groundwater seep, was also analyzed for radionuclides, as it was felt that this material would be representative of the suspended solids in the whole water sample (Table 5.11). It is noteworthy that the very high concentrations of U-238 decay chain radionuclides in groundwater from the exposed ore body do not result in obviously higher concentrations of the same radionuclides in Pointer Lake, which drains the area, relative to other lakes in the vicinity (Table 5.10). This indicates that the flux of groundwater from the 0.25 km^2 area of the ore body into Pointer Lake is insignificant relative to the surface water runoff and groundwater flux from the 82 km^2 drainage basin of the lake.

5.3 Monitoring Implications

Water quality monitoring will be required to measure the effectiveness of environmental controls at the Kiggavik project site, and will be included as conditions of the N.W.T. Water Board and Atomic Energy Control Board operating licences. Important areas to monitor include waters downstream of the point of effluent release (the outlet of Pointer Lake), and upstream reference locations unaffected by the project. Dissolved oxygen levels in Judge Sissons Lake should be measured to trace the effects of treated sewage on the lake, particularly under ice. Heavy metals and trace elements should be monitored to document any changes resulting from site activities, and to evaluate the accuracy of impact predictions. Radionuclides should be monitored downstream to trace the quantities transported downstream (versus the quantities lost to lake sediments). For those parameters predicted to be affected by mining activities, monitoring should extend from the local level (e.g., Judge Sissons Lake) to the regional level (Aniguq River), with the frequency of monitoring determined according to the likelihood of measuring change.

TABLE 5.11: RADIONUCLIDE CONCENTRATIONS[1] IN GROUNDWATER FROM THE MAIN ZONE ORE BODY AND A NEARBY REFERENCE SITE[2]

	U	Th-230	Ra-226	Pb-210	Po-210	Th-232	Ra-228	Th-228
Main Zone Groundwater								
o Unfiltered total conc. (ug/L or Bq/L)[3]	2,100 (1,300)[6]	6.1	12	5.8	0.78	-	-	L 0.13
o Inferred dissolved conc. (ug/L or Bq/L)[4]	1,700	2.6	9.6	3.5	-	-	-	-
o Solids conc. (ug/g or Bq/g)	13,000	114	77	73	-	-	L 0.82	-
o Inferred particulate conc. (ug/L or Bq/L)[5]	400	3.5	2.4	2.3	-	-	L 0.025	-
Sauna Lake Groundwater								
o Unfiltered total conc. (ug/L or Bq/L)	17 (2.3)[6]	0.078	0.057	0.11	0.050	0.0028	-	0.038
o Inferred dissolved conc. (ug/L or Bq/L)[3]	17	-	0.053	0.089	-	-	-	-
o Solids conc. (ug/g or Bq/g)	27	-	0.23	1.28	-	-	0.17	-
o Inferred particulate conc. (ug/L or Bq/L)[4]	0.43	-	0.0037	0.021	-	-	0.0028	-

1 ug/L or ug/g for U, Bq/L or Bq/g for other radionuclides.
2 From a seep located at the toe of the cliff bordering the north shore of Sauna Lake.
3 Unfiltered total concentrations based on analysis of pre-concentrated samples of 180 L original volume.
4 Dissolved radionuclide concentration = unfiltered total concentration minus inferred particulate concentration.
5 Inferred particulate concentration is the contribution to the total radionuclide concentration in unfiltered water, based on 31 mg/L of suspended solids in the Main Zone sample, and 16 mg/L in the reference site sample.
6 Uranium concentrations in whole (unconcentrated) water samples.

6.0 SEDIMENT QUALITY

6.1 Physical and Chemical Properties

Detailed physical and chemical properties of surficial sediments collected from Kiggavik area lakes in 1988, 1986 and 1979 are provided in Tables 6.1, 6.2 and 6.3, respectively. Ranges in sediment quality conditions reported for each survey year are summarized in Table 6.4.

In 1979, sediments were collected using a KB corer at various lake stations, and both surface and subsurface samples were analyzed for metal concentrations in whole sediments (Table 6.1). Samples were collected in 1986 from apparent depositional areas within each lake surveyed. The 1986 Sisson's Lake sample was collected from a depth of about 5 m offshore from the mouth of the Willow Lake watershed. Samples were collected from areas near the deepest parts of smaller lakes, although for very shallow and relatively large lakes such as Pointer, Caribou and Boulder, zones of soft sediment accumulation were difficult to find, and repeated attempts were generally required before samples could be recovered. Sediment samples were collected in 1988 from the deep parts of each lake surveyed, with the exception of Pointer Lake. In Pointer Lake, samples were collected in the northern finger of the lake at two locations - Station 1 located in mid-lake 800 m south of the northern end of the lake, and Station 2, 800 m south of Station 1. Substrates in the main body of Pointer Lake consisted of sticky clay, sand and rock, and did not appear to be indicative of depositional conditions.

Kiggavik area lake sediments are generally light brown, and consist of varying amounts of sand, silt and clay-size particles (Table 6.3). Silt was the dominant particle size category in all lakes except Sisson's, which had nearly equal amounts of fine sand, very fine sand, silt and clay. Differences in sediment texture between smaller lakes and Sisson's can be attributed to the much greater depth of Sisson's and the different depositional environment provided in deep lakes.

Lake sediments consist of organic and inorganic matter introduced through erosion of soils and other geologic materials in the watershed, and through the deposition of particulate mineral matter and organic material produced in the lake, generally by planktonic organisms. Lake sediments act as sinks for many elements, including

TABLE 6.1: QUALITY OF SURFICIAL LAKE SEDIMENTS IN KIGGAVIK AREA LAKES, JULY 1988

	Pointer Lake-1		Pointer Lake-2A		Pointer Lake-2B		Pointer Lake-2C		Jaeger Lake	
	Whole	Fines*	Whole	Fines	Whole	Fines	Whole	Fines	Whole	Fines
% coarse sand (0.5-1 mm)	0	-	0	-	0	-	0	-	1.01	-
% medium sand (0.25-0.5 mm)	0.62	-	1.28	-	1.08	-	7.66	-	2.54	-
% fine sand (0.088-0.25 mm)	3.71	-	3.20	-	3.54	-	12.31	-	16.71	-
% very fine sand (0.0625-0.088 mm)	49.41	-	13.15	-	13.67	-	26.29	-	39.49	-
% silt (0.0039-0.0625 mm)	37.69	-	71.53	-	70.18	-	42.96	-	27.69	-
% clay (L 0.0039 mm)	8.59	-	10.82	-	11.54	-	10.77	-	12.47	-
Loss-on-ignition (%)	8.5	-	12.7	-	12.2	-	11.1	-	16.5	-
Cation Exchange Capacity (meq/100 g)	3.1	-	4.8	-	6.4	-	4.8/5.8	-	11.0/11.0	-
Total Kjeldahl-N	3,200	-	4,800	-	4,700	-	2,900	-	8,600	-
Chemical Oxygen Demand (%)	1.41	-	1.68	-	1.83	-	1.49/1.23	-	1.75	-
Total P	820	-	870	-	930	-	840	-	950	-
Al (mg/g)	10.1	10.2	14.2	12.2	13.3	12.8	13.0	12.2	13.3	14.8
As	3.0	-	4.0	-	4.0	-	4.5	-	3.0	-
Ba	157	158	210	187	200	191	192	185	280	280
Ca (mg/g)	2.7	2.8	2.9	2.8	3.0	2.9	2.8	2.7	3.1	3.0
Cd	0.15	-	0.15	-	0.20	-	0.20	-	0.25	-
Co	5	-	6	-	6	-	6	-	6	-
Cr	27	-	36	-	35	-	34	-	34	-
Cu	14	-	23	-	23	-	25	-	29	-
Fe (mg/g)	9.6	-	11.6	-	12.1	-	10.8	-	9.3	-
Hg	L 0.02	-	0.04	-	0.04	-	0.08	-	0.06	-
Mg (mg/g)	3.5	3.5	4.6	4.2	4.6	4.5	4.4	4.2	4.6	4.6
Mn	108	110	136	124	134	135	130	123	147	145
Ni	17	17	22	21	22	23	21	21	24	26
Pb	8.8	7.2	11.8	10.8	12.0	13.0	11.6	12.0	12.8	14.6
Se	L 0.5	-	L 0.5	-	L 0.5	-	L 0.5	-	L 0.5	-
Sr	85	85	98	87	96	89	93	84	84	82
Zn	41	38	58	52	61	61	69	65	60	59

Notes:

L = less than.

* Fines = fraction less than 63 microns (silt + clay).

Concentrations are ug/g unless indicated otherwise.

Multiple entries for single stations and parameters represent laboratory replicates.

Pointer Lake samples 2A-C are field replicates.

TABLE 6.2: QUALITY OF SURFICIAL SEDIMENTS IN KIGGAVIK AREA LAKES, JULY 1986

	Skinny	Boulder	Ridge	Cirque	Escarpment	Felsenmeer	Lin	Willow	Caribou	Sisson's
Loss-on-ignition (%)	9.7	10.5	13.0	18.2	14.0/14.0	10.3	28	8.9	7.5	2.4
Total Kjeldahl-N	140	4,800	6,000	7,700	1,000/1,400	2,700	8,100	6,600	2,600	790
Chemical Oxygen Demand (%)	3.6	4.3	2.7	6.7	3.6	3.4	6.7	2.3	1.9	0.75/0.82
Total P	1,260	830	4,700	1,160	1,930/1,860	1,080	1,150	1,210	1,170	700
Al (mg/g)	12.5	6.3	16.8	23.0	19.3/21.0	19.3	14.3	14.8	14.1	5.3
As	3.0	3.0	60	-	30/34	4.5	2.0	6.0	4.0	2.0
Ba	320	158	620	550	440/440	330	350	240	178	93
Be	2	L 1	2	2	2/2	L 1	1	1	1	L 1
Ca (mg/g)	2.1	1.94	2.7	2.5	1.65/1.69	2.5	4.5	3.6	3.6	1.89
Cd	-	L 1	-	L 1	-	L 1	L 1	L 1	L 1	L 1
Co	6	2	10	7	17/15	7	3	8	8	2
Cr	26	19	52	63	47/44	46	34	48	54	16
Cu	29	17	39	59	36/34	23	63	16	19	4
Fe (mg/g)	3.1	9.1	85	20	94/92	22	11.8	2.7	2.0	11.5
Hg	0.11	0.03	0.05	0.06	0.06	0.05/0.04	0.06	0.02	0.01	L 0.01
K	2.6	1.6	4.1	6.2	4.1/5.0	4.6	3.4	3.1	2.7	1.15
Mg (mg/g)	3.7	3.1	6.0	7.3	5.1/5.1	6.2	5.5	6.4	7.4	2.4
Mn	280	107	700	280	670/640	220	120	220	220	119
Mo	L 2	L 2	6	2	4/4	L 2	L 2	L 2	L 2	L 2
Na	300	170	480	350	430/440	300	270	360	400	125
Ni	16	13	32	42	28/26	27	29	26	29	8
Pb	14	10	14	20	16/14	16	18	12	10	4
Se	L 0.5	L 0.5	L 0.5	-	L 0.5/L 1	L 0.5	L 0.5	L 0.5	L 0.5	L 0.5
Sr	14	13	20	18	18/20	24	23	29	25	12
Zn	66	38	73	83	99/96	56	78	69	64	25

Notes:

L = less than.

Concentrations are ug/g dry weight unless indicated otherwise.

Multiple entries for single parameters and stations represent laboratory replicates.

TABLE 6.3: AVERAGE QUALITY OF SURFICIAL AND SUBSURFACE SEDIMENTS COLLECTED IN KIGGAVIK AREA LAKES, 1979

	Pointer		Scotch		Jaeger		Sisson's	
	Surface	Subsurface	Surface	Subsurface	Surface	Subsurface	Surface	Subsurface
No. of Samples	10	7	2	2	1	0	14	14
As	1.5	1.98	0.86	1.39	2.32	-	4.48	2.32
Cd	L 0.5	L 0.5	L 0.5	L 0.5	L 0.5	-	L 0.5	L 0.5
Cr	85.5	60.7	85.0	60.0	100.0	-	82.5	73.2
Cu	18.0	15.0	22.5	15.0	15.0	-	14.4	15.0
Hg	0.0141	0.0073	0.0265	0.0125	0.0060	-	0.0174	0.0170
Pb	L 5.0	L 5.0	L 5.0	L 5.0	L 5.0	-	L 5.0	L 5.0
Se	0.052	0.059	0.090	0.130	0.020	-	0.034	0.043
Te	L 0.1	L 0.1	L 0.1	L 0.1	L 0.1	-	L 0.1	L 0.1

Notes:

Concentrations are ug/g dry weight, except for As, Te and Se which are in ug/g wet weight.

L = less than.

Surface: top 3 cm
Subsurface: 10-13 cm depth

waterborne materials that might be released into the environment through mining and milling activities. Sediment chemistry can thus provide a means of environmental monitoring the release of metals and other materials by mining and milling activities.

Based on the 1979 results, there do not appear to be consistent differences in metal concentrations between surface and subsurface layers, with the exception of chromium. The surface sediments show a slight enrichment in chromium relative to the subsurface layer. Because there are no local contamination sources that would explain this enrichment, it is probably a natural phenomenon resulting from variations in reduction-oxidation potential with depth in the sediment.

Soft sediments in Kiggavik area lakes typically have organic contents (loss-on-ignition) of 9 to 18% by weight, and have varying concentrations of nutrients (nitrogen and phosphorus). Major mineral constituents include aluminum, iron and calcium. Silicates are also expected to be of major importance, although silicate concentrations were not measured. For the most part, the elemental composition of Kiggavik lake sediments is similar to the composition of typical soils (Table 6.4).

6.2 Radionuclides

Concentrations of radionuclides in Kiggavik area lake surface sediments, based on samples collected in 1979, 1986 and 1988, are provided in Table 6.5, while Table 6.6 presents a data summary by year, and relevant comparative data on Saqvaqjuac lake sediments. In general, radionuclide levels in the Kiggavik area and Saqvaqjuac lake sediments are similar, and concentration ranges for each radionuclide overlap. Higher maximum concentrations, however, generally occur in Kiggavik area lakes for U, Th-230 and Ra-226, possibly reflecting the mineralogy in the area. Lead-210 concentrations in surficial sediments are primarily the result of natural atmospheric fallout, and are probably a function of sedimentation rates rather than of radionuclide losses from adjacent watersheds.

Lake sediments generally act as a sink for waterborne radionuclides. They can also act as a source of radionuclides to surface water through diffusion, bottom current effects, and disturbance by bottom organisms (i.e., benthos and bottom-feeding fish). As radionuclides in the water column form precipitates or complex with other water column

TABLE 6.4: RANGES IN QUALITY OF WHOLE, SURFICIAL SEDIMENTS FOR SELECTED PARAMETERS IN KIGGAVIK AREA LAKES, 1979, 1986, 1988

	1979[1]	1986	1988[2]	Global Soils[3]
Loss-on-ignition (%)	-	2.4-28	8.5-17.8	-
Total Kjeldahl-N	-	140-8,100	2,900-8,600	-
Total P	-	700-4,700	820-2,400	650
Al (mg/g)	-	5.3-23	10.1-26.0	71
As	(0.86-4.48)[4]	2.0-60	3.0-21.5	6
Ba	-	93-620	157-480	500
Ca (mg/g)	-	1.65-4.5	2.5-3.1	13.7
Cd	L 0.5	L 1	0.15-0.60	-
Cr	82.5-85.5	2-17	27-66	100
Cu	14.4-22.0	4-63	14-54	20
Fe (mg/g)	-	2.0-94	9.3-50.0	38
Hg	(0.0141-0.0265)[4]	L 0.01-0.11	L 0.02-0.08	-
Ni	-	8-42	17-47	400
Pb	L 5	4-20	8.8-12.8	10
Zn	-	25-99	41-143	50

[1] 1979 ranges based on mean values for surface sediments given in Table 6.1.

[2] 1988 ranges based on whole sediments.

[3] From Koranda et al. (1981).

[4] 1979 results expressed on a wet weight basis for Hg and As.

Notes: L = less than.

Concentrations are ug/g dry weight unless indicated otherwise.

TABLE 6.5: CONCENTRATIONS AND ACTIVITIES OF U-238 AND Th-232 DECAY CHAIN RADIONUCLIDES IN SEDIMENTS FROM KIGGAVIK AREA LAKES

	U (ug/g)	Th-230 (Bq/g)	Ra-226 (Bq/g)	Pb-210 (Bq/g)	Po-220 (Bq/g)	Th-232 (Bq/g)	Ra-228 (Bq/g)	Th-228 (Bq/g)
July 1988								
Pointer Lake:								
o Station 1	3.0	0.11±0.02	0.085±0.008	L 0.05	0.045±0.005	0.065±0.015	L 0.2	0.075±0.015
o Station 2A[1]	4.0	-	0.025±0.005	0.06±0.02	0.080±0.008	-	-	-
o Station 2C[1]	4.3	-	0.037±0.006	L 0.05	0.050±0.006	-	-	-
o Station 2D[1]	3.2	-	0.030±0.006	0.05±0.02	0.045±0.006	-	-	-
Jaeger Lake	4.6	0.05±0.015	0.027±0.005	0.15±0.02	0.22±0.02	0.055±0.015	L 0.2	0.080±0.020
Scotch Lake	4.4	0.030±0.010	0.012±0.005	0.05±0.02	0.090±0.010	0.050±0.016	L 0.2	0.055±0.015
Crash Lake	4.5	0.050±0.015	0.065±0.010	0.08±0.02	0.090±0.010	0.095±0.020	L 0.2	0.070±0.015
Sissons Lake (13 m)	5.8	0.040±0.010	0.045±0.010	0.07±0.02	0.095±0.010	0.011±0.020	L 0.2	0.055±0.015
July 1986								
Skinny Lake	7.2	0.11	0.050	0.06	-	0.084	-	-
Boulder Lake	2.6	0.03	0.018	0.15	-	0.042	-	-
Ridge-Cirque[2]	3.7	0.04	0.045	0.13	-	0.066	-	-
Escarpment-Felsenmeer[2]	4.6	0.05	0.051	0.16	-	0.088	-	-
Lin	4.2	0.04	0.030	0.20	-	-	-	-
Willow	4.1	0.03	0.035	0.06	-	0.063	-	-
Caribou	3.3	0.15	0.030	L 0.03	-	0.065	-	-
Sissons	2.3	0.01	0.017	L 0.03	-	0.061	-	-
Sissons - Interlab Split	2.6	0.016±0.004	0.011±0.004	0.06±0.02	0.090±0.014	L 0.005	-	0.017±0.005
Sissons + 10% Standard[3]	7.80	0.37	0.41	0.37	-	0.106	-	-
o Consensus Value Range	-	0.34-0.56	0.54-0.62	0.46-0.50	-	0.11-0.13	-	-
Sissons + 25% Standard[3]	15.28	1.00	1.02	1.03	-	0.186	-	-
o Consensus Value Range	-	0.83-1.4	1.3-1.5	1.1-1.2	-	0.19-0.24	-	-
Summer 1979[4]								
Pointer Lake:								
o Surface Mean (n=10)	2.6	0.032	0.039	0.084	-	0.046	-	0.046
Standard Deviation	(0.90)	(0.022)	(0.0058)	(0.054)	-	(0.033)	-	(0.035)
o Bottom Mean (n=7)	2.3	0.027	0.039	0.069	-	0.043	-	0.043
Standard Deviation	(1.3)	(0.016)	(0.015)	(0.034)	-	(0.021)	-	(0.020)
Scotch Lake:								
o Surface Mean (n=2)	3.0	0.044	0.032	0.053	-	0.052	-	0.048
Standard Deviation	(0.28)	(0)	(0.0078)	(0.062)	-	(0)	-	(0.0052)
o Bottom Mean (n=14)	3.7	0.035	0.030	0.0093	-	0.055	-	0.057
Standard Deviation	(0.35)	(0.0026)	(0.0052)	(0)	-	(0)	-	(0.0026)
Sissons:								
o Surface Mean (n=14)	2.0	0.027	0.031	0.051	-	0.036	-	0.040
Standard Deviation	(1.3)	(0.018)	(0.012)	(0.056)	-	(0.021)	-	(0.026)
o Bottom Mean (n=14)	3.0	0.034	0.032	0.035	-	0.045	-	0.051
Standard Deviation	(1.7)	(0.016)	(0.014)	(0.044)	-	(0.021)	-	(0.024)

1 Samples A, C and D are field replicate samples from Pointer Lake Station 2.

2 Two-lake composite samples.

3 CANMET tailings standard, UTS-2.

4 Mean values from several stations and duplicate samples in Pointer Lake and Sissons Lake; one station sampled in duplicate in Scotch Lake. Values below detection limit were assumed to equal half of the detection limit.

Surface - top 3 cm in core; bottom - 10 to 13 cm below core surface.

TABLE 6.6: BACKGROUND RANGES OF RADIONUCLIDE CONCENTRATIONS AND ACTIVITIES IN SURFICIAL SEDIMENTS OF KIGGAVIK AREA LAKES, AND COMPARATIVE REGIONAL DATA

	1988[1]	1986[1]	1979[2]	Saqvaqjuac Lakes[3]
U (ug/g)	3.0-5.8	2.3-7.2	L 0.5-4.8	1.6-5.5[4]
Th-230 (Bq/g)	0.03-0.11	0.01-0.11	L 0.01-0.059	0.014-0.048
Ra-226 (Bq/g)	0.012-0.085	0.017-0.051	0.01-0.052	0.008-0.023
Pb-210 (Bq/g)	L 0.05-0.15	L 0.03-0.2	L 0.02-0.21	0.040-0.247
Po-210 (Bq/g)	0.045-0.22	-	-	-
Th-232 (Bq/g)	0.011-0.095	0.042-0.088	L 0.01-0.063	0.028-0.101
Ra-228 (Bq/g)	L 0.2	-	-	-
Th-228 (Bq/g)	0.055-0.080	-	L 0.01-0.089	0.044-0.155

[1] This study

[2] Urangesellschaft (1979)

[3] Brunskill et al. (1986); range of mean values for four lakes

[4] U concentrations

particulates such as phytoplankton, they eventually tend to settle to the lake bottom. Thus, sediments may be expected to accumulate radionuclides released to surface waters from mining and milling operations. When releases of radionuclides are reduced following the cessation of mining and milling, concentrations may be expected to gradually fall in the water column, and the sediments to become net sources of radionuclides to the water column. Thus, a sediment monitoring component for radionuclides will be a key element of the environmental monitoring program for any development at Kiggavik.

6.3 Sediment Accumulation Rates

The rate of sediment accumulation of radionuclides and stable metals depends on the total loading from the watershed, the sediment-water partitioning of the stable and radioactive elements, and on the sedimentation rate. Sedimentation rates were measured in Pointer Lake and Judge Sissons Lake using the Pb-210 method (Robbins, 1978). This method has been used in measuring sedimentation in other Arctic lakes (e.g., Cornwell, 1985; Brunskill et al., 1986), as well as many other lakes. Lead-210 dating will probably not be useful in Kiggavik area lakes receiving mill effluents in the future, due to the disruption of the natural radionuclide loadings. This problem was documented by McKee et al. (1987) in Quirke Lake, a waterbody affected by uranium mining and milling near Elliot Lake, Ontario.

Sediment cores were collected in duplicate by a KB corer (Brinkhurst et al., 1969) outfitted with 4.7-cm (inside diameter) polycarbonate core tubes. Cores were collected from two depths (11 m and 13 m) in Judge Sissons Lake, and one depth (about 1.8 m) at Station 2 in Pointer Lake. Attempts to collect cores from the main body of Pointer Lake (depths of 2 to 2.3 m), and from depths below about 10 m in the eastern basin of Sissons Lake were unsuccessful, apparently due to the presence of rock, coarse sand or dense clay on the sediment surface. Little net deposition may be expected to occur in these areas due to frequent wind-driven sediment resuspension.

Core samples were extruded within 12 hours of sampling by pushing a piston up from the bottom of the core tube, and slicing off 0.5- to 2-cm sections in a plastic collar. Measurements were periodically checked by determining the height of the remaining column of sediment during the extrusions, and sediment depths were adjusted accordingly. Sections from each duplicate set of cores were combined down to a depth of 2 to 2.5 to ensure an adequate mass for analysis.

Sediment slices were subsequently prepared by determining their dry bulk densities, and grinding them with a mortar and pestel for Pb-210 analysis. Sediment dry bulk densities are shown in Table 6.7. These data show that the sediments in the Pointer cores had a greater density (and lower water content) than did the Sissons cores. This is probably related to the finer texture and lower organic content of the Pointer sediments (Table 6.2).

Sediment core slices were analyzed for Pb-210 indirectly by measuring Po-210, as described by Evans and Rigler (1980). All sediment cores were analyzed by Chalk River Nuclear Laboratories.

Semi-logarithmic plots of Pb-210 against cumulative dry mass were drawn, as illustrated in Figure 6.1. Deviation from log-linearity may occur near the surface due to disturbance by benthic organisms and currents, and at depth due to Pb-210 in-growth from Ra-226.

Sediment accumulation rates were determined from the radioactive decay constant for Pb-210 (0.03114 yr^{-1}), and the slope of the regression line of ln (C_w-C) on W, where:

> C_w is the concentration of Pb-210 at depth w,
> C is the concentration of supported Pb-210 (assumed to be equal to the concentration in the deepest core slice below the log-linear section), and
> W is the depth, expressed as g dry mass/cm^2.

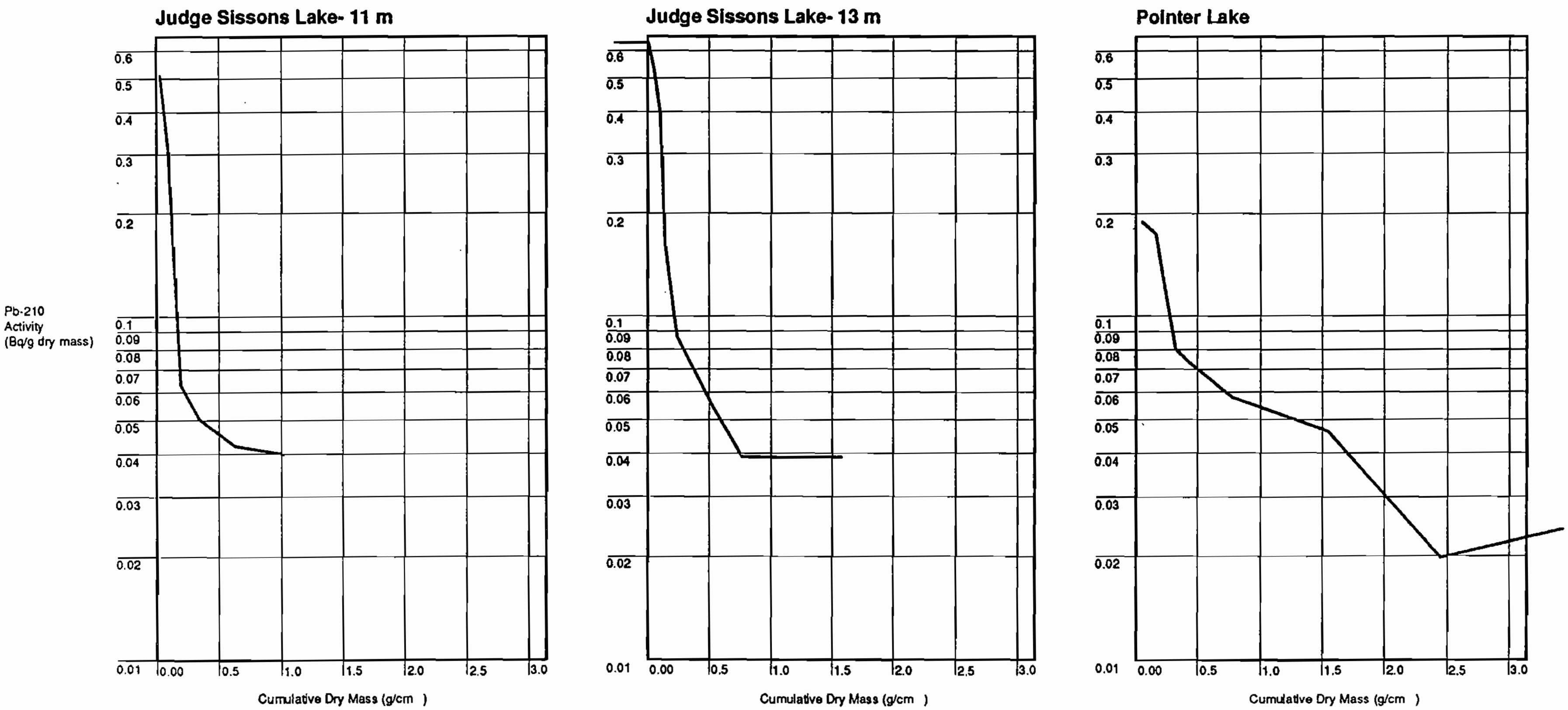
Depth is expressed on a cumulative dry mass basis to avoid the problem caused by sediment compaction through time.

The regression line was, in each case, based on the three points of highest activity below the surface sample or surface two samples in the log-linear section. The surface layer was not used due to the potential effects of sediment mixing in the surface, although only the Pointer cores showed a substantial deviation from log-linearity at the surface (e.g., Figure 6.1). The sedimentation rate, in $g \cdot cm^{-2} \cdot yr^{-1}$, is calculated as 0.03114/k, where k is the slope of the regression line.

TABLE 6.7: DRY BULK DENSITIES (g/mL) OF SEDIMENT CORE INTERVALS (cm) FROM POINTER LAKE AND SISSONS LAKE

Pointer Lake - 1.8 m		Sissons Lake - 11 m		Sissons Lake - 13 m	
Core Interval (cm)	Density (g/mL)	Core Interval (cm)	Density (g/mL)	Core Interval (cm)	Density (g/mL)
0-0.59	0.139	0-0.48	0.076	0-0.56	0.062
0.59-1.17	0.222	0.48-0.95	0.114	0.56-1.11	0.091
1.17-1.76	0.251	0.95-1.43	0.095	1.11-1.67	0.073
1.76-2.34	0.266	1.43-1.91	0.110	1.67-2.22	0.107
2.34-3.51	0.346	1.91-2.86	0.152	2.22-3.33	0.117
3.51-4.68	0.376	2.86-3.81	0.142	3.33-4.45	0.133
4.68-5.85	0.385	3.81-4.76	0.136	4.45-5.56	0.118
5.85-7.02	0.435	4.76-5.72	0.174	5.56-6.67	0.116
7.02-8.19	0.439	5.72-6.67	0.212	6.67-7.78	0.134
8.19-9.36	0.487	6.67-7.62	0.223	7.78-8.89	0.140
9.36-10.53	0.506	7.62-8.57	0.231	8.89-10.0	0.196
10.53-11.70	0.480	8.57-9.53	0.231	10.0-11.1	0.158
11.7-14.04	0.448	9.53-11.4	0.269	11.1-13.3	0.152
		11.43-18.4	0.457		

FIGURE 6.1
Lead-210 Profiles in Sediment Cores from Judge Sissons and Pointer Lakes



Sedimentation rates in the Kiggavik area cores were:

	Pointer Lake	Sissons - 11 m	Sissons - 13 m
$g \cdot m^{-2} \cdot yr^{-1}$	300	11	20
mm/yr	1.6	0.11	0.26

The lower numbers listed above represent the average annual depth of accumulation based on mass accumulation rates and on the dry bulk densities for the surface four core slices (top 2 to 2.5 cm).

In the 11 m Sissons cores, a sticky grey clay was encountered below a depth of 18.4 cm. This is probably a layer deposited during deglaciation, which occurred in the area about 6,000 to 8,000 years B.P. The total mass accumulated above this layer was 5.3 $g \cdot cm^{-2}$, which is equivalent to an overall average annual rate of 7.6 $g \cdot m^{-2} \cdot yr^{-1}$ over 7,000 years. This is about 70% of the 11 $g \cdot m^{-2} \cdot yr^{-1}$ measured in recent sediments by Pb-210, probably reflecting an increase in sedimentation rate in recent history relative to earlier post-glacial time. These changes can be attributed to various factors, including glacial rebound and changes in erosion rates, climatic vegetative changes, and changes in the lake basin itself. Post-depositional oxidation of organic matter may also be a factor contributing to the lower rates occurring over the long-term.

Sedimentation rates of 11 to 20 $g \cdot m^{-2} \cdot yr^{-1}$ in the depositional zone of Sissons Lake are at the low end of the rates reported for other Arctic lakes. Other documented rates include 12 to 73 $g \cdot m^{-2} \cdot yr$ for an Alaskan lake (Cornwell, 1985), 31 $g \cdot m^{-2} \cdot yr^{-1}$ for a whole-lake average in Char Lake (deMarch, 1978), and 22 to 56 $g \cdot m^{-2} \cdot yr^{-1}$ for a whole-lake average in Saqvaqjuac lakes (Brunskill et al., 1986). These low Kiggavik sedimentation rates reflect a condition of low productivity and limited sediment input from shoreline erosion and tributary streams to Sissons Lake. Whole-lake average sedimentation rates are probably less than rates measured at the 11 m and 13 m stations because most of the lake area (about 93%) is shallower than 10 m, the estimated boundary between the depositional and non-depositional zones. If deposition occurs only at depths of greater than 10 m, the whole-lake average sedimentation rate in Judge Sissons Lake is only about 1 $g \cdot m^{-2} \cdot yr^{-1}$. This rate, however, appears unreasonably low based on published sedimentation rates in other Arctic lakes. If radionuclide transport proves to be sensitive to sedimentation rate, it would be prudent to carry out a more detailed reconnaissance of depositional characteristics in Judge Sissons Lake during pre-operational baseline monitoring.

The estimated sedimentation rate of 300 $g \cdot m^{-2} \cdot yr^{-1}$ for the northern "finger" of Pointer Lake is high relative to Sissons Lake values, probably due to high rates of sediment loadings from tributaries draining from the north, and to the apparent focussing of all deposition in this small area (about 7.5% of the total lake area). Based on this surface area consideration, the whole-lake average sedimentation rate in Pointer Lake is estimated to be 7.5% of 300 $g \cdot m^{-2} \cdot yr^{-1}$, or 20 to 25 $g \cdot m^{-2} \cdot yr^{-1}$. The log Pb-210-cumulative mass relationship for Pointer Lake showed considerable irregularity, suggesting either variable deposition rates or frequent post-depositional disturbance, probably by wind-driven current action or occasional ice scouring. Thus, a wide uncertainty band of $\pm$ 50% may be reasonably assumed around the 300 $g \cdot m^{-2} \cdot yr^{-1}$ value. This rate is more typical of the higher end of ranges reported in southern Shield lakes (e.g., Evans et al., 1980; McKee et al., 1987).

6.4 Monitoring Implications

As sediments are deposited rather slowly in Kiggavik study area lakes (e.g., 0.11 mm to 0.26 mm/yr in Judge Sissons Lake), monitoring of sediment quality downstream of project activities should focus on very surficial layers in order to permit any detection of sediment quality change. Sediment quality monitoring should be carried out to trace the movement of radionuclides and other materials released in the treated mill effluent through the aquatic environment, particularly since sedimentation is an important means of buffering the downstream environment from changes in water quality.

7.0 AQUATIC BIOLOGY

7.1 Phytoplankton

Phytoplankton samples were collected from four Kiggavik area lakes in 1979 (Pointer, Jaeger, Scotch and Judge Sissons) and from five Kiggavik area lakes in 1989 (Ridge, Pointer, Jaeger, Sissons and Cirque).

Samples were collected as whole water samples from mid-depth in each lake in 1979, and from lake outlets in 1989. Samples were preserved in Lugol's iodine solution. Biomass was determined by measuring cell dimensions to calculate cell volumes, which are used to calculate biomass based on an assumed density of 1 g/cm^3. Phytoplankton were identified and enumerated using an inverted microscope following the Utermohl technique. Phytoplankton survey data for 1989 are listed in Tables 7.1 to 7.5, while 1979 data are reported in Urangesellschaft (1979).

Phytoplankton communities in Kiggavik study area lakes for 1979 and 1989 showed characteristics typical of unproductive Shield lakes. Total biomasses were low, generally ranging between 100 and 300 mg/m^3. For every lake except Ridge Lake in 1989, and for all lakes in 1979, Chrysophyceae were dominant, with Chlorophyceae, Chlorophyta and Cryptophyceae of secondary importance. The phytoplankton community of Ridge Lake was dominated by the diatom Tabellaria flocculosa in the 1989 survey. Biomasses of 200 to 2,000 mg/m^3 are typical of Shield lakes in the Experimental Lakes Area (northwestern Ontario), with Chryosphyceae also predominating there (Schindler and Holmgren, 1970). Phytoplankton communities are very dynamic, and respond over short time periods (days to weeks) to changing conditions. Because of their dynamic nature, it is very difficult to measure significant changes in community structure. For this reason, phytoplankton is seldom used to monitor the effects of mining activities or other industrial development.

7.2 Zooplankton

Zooplankton communities were studied in Kiggavik area lakes in 1979 and 1989.

The zooplankton of Pointer Lake were sampled on nine occasions during the 1979 ice-free season. Zooplankton communities in Judge Sissons Lake were sampled three times and

TABLE 7.1: SPECIES, DENSITIES AND BIOMASSES OF PHYTOPLANKTON IN KIGGAVIK AREA LAKES, AUGUST 1989 - RIDGE LAKE

Species	Cells/L	mg/m^3	Total Biomass per Group (mg/m^3)	Percent of Total Biomass (%)
CYANOPHYTA			3.057	1.1
Oscillatoria planctonica	8,550	1.791		
Anabaena planctonica	2,850	0.967		
Aphanocapsa delicatissima	2,850	0.252		
Chroococcus dispersus	2,850	0.048		
CHLOROPHYTA			46.647	17.3
Elakatothrix lacustris	5,700	0.282		
Monoraphidium setiforme	25,650	2.507		
Spondylosium planum	2,850	0.570		
Ankistrodesmus falcatus var.	76,950	3.807		
Mougeotia sp.	2,850	15.042		
Arthrodesmus incus	2,850	1.710		
Euastrum binale	2,850	2.394		
Oocystis submarina	2,850	0.860		
Tetraedron minimum	2,850	0.570		
Cosmarium bioculatum	2,850	2.394		
Oedogonium sp.	2,850	6.447		
Sphaerocystis schroeteri	2,850	3.056		
Cosmarium subtumidum	2,850	6.840		
Ankistrodesmus falcatus v. mira	2,850	0.168		
CHRYSOPHYCEAE			35.088	13.0
Bitrichia chodatii	2,850	0.167		
Uroglena volvox	22,800	7.640		
Dinobryon bavaricum	2,850	1.719		
Dinobryon crenulatum	5,700	0.597		
Mallomonas akrokomonas	5,700	2.089		
Uroglena americana	5,700	0.860		
Chromulina 4 um	312,000	10.455		
Erkenia subaequiciliata	48,000	0.905		
Dinobryon borgii	24,000	1.407		
Dinobryon petiolatum	24,000	1.206		
Chrysophyte unidentified	24,000	1.608		
Rhizochrysis sp.	24,000	6.434		

TABLE 7.1: SPECIES, DENSITIES AND BIOMASSES OF PHYTOPLANKTON IN KIGGAVIK AREA LAKES, AUGUST 1989 - RIDGE LAKE

Species	Cells/L	mg/m^3	Total Biomass per Group (mg/m^3)	Percent of Total Biomass (%)
BACILLARIOPHYCEAE			150.483	55.9
Tabellaria flocculosa	39,900	127.680		
Navicula sp.	5,700	0.846		
Cyclotella sp.	2,850	17.549		
Diatom girdle view	2,850	1.910		
Asterionella formosa	2,850	2.068		
Rhizosolenia eriensis	2,850	0.430		
CRYPTOPHYCEAE			31.411	11.7
Cryptomonas erosa	5,700	10.314		
Cryptomonas platyuris	2,850	10.237		
Cryptomonas marsonii	2,850	1.209		
Rhodomonas lacustris	11,400	5.730		
Rhodomonas minuta v. nannopl	48,000	2.513		
Katablepharis ovalis	24,000	1.407		
DINOPHYCEAE			2.659	1.0
Gymnodinium varians	5,700	2.659		
TOTAL COUNT (cells/L)	815,850			
TOTAL BIOMASS (mg/m^3)	269.346			

TABLE 7.2: SPECIES, DENSITIES AND BIOMASSES OF PHYTOPLANKTON IN KIGGAVIK AREA LAKES, AUGUST 1989 - CIRQUE LAKE

Species	Cells/L	mg/m^3	Total Biomass per Group (mg/m^3)	Percent of Total Biomass (%)
CYANOPHYTA			0.382	0.2
Chroococcus limneticus	2,850	0.382		
CHLOROPHYTA			22.581	11.4
Elakatothrix gelatinosa	2,850	0.269		
Elakatothrix lacustris	5,700	0.403		
Crucigenia quadrata	34,200	7.934		
Cosmarium depressum	2,850	5.198		
Oocystis solitaria	2,850	1.337		
Gloeocystis planctonica	2,850	3.820		
Chlamydomonas 8x6 um	24,000	3.619		
CHRYSOPHYCEAE			130.732	66.1
Mallomonas akrokomonas	19,950	7.312		
Dinobryon bavaricum	71,250	69.757		
Uroglena americana	14,250	16.713		
Bitrichia chodatii	8,550	0.783		
Ochromonas 6x5 um	408,000	32.044		
Chromulina 4 um	96,000	3.217		
Erkenia subaequiciliata	48,000	0.905		
BACILLARIOPHYCEAE			12.944	6.5
Cyclotella sp.	2,850	1.119		
diatom girdle view	2,850	10.446		
Synedra acus v. radians	5,700	1.379		
CRYPTOPHYCEAE			31.124	15.7
Rhodomonas lacustris	2,850	1.024		
Cryptomonas rostrata	2,850	7.521		
Cryptomonas erosa	5,700	10.314		
Cryptomonas marsonii	5,700	1.910		
Katablepharis ovalis	48,000	2.815		
Rhodomonas minuta v. nanno	72,000	7.540		
TOTAL COUNT (cells/L)	892,650			
TOTAL BIOMASS (mg/m^3)	197.762			

TABLE 7.3: SPECIES, DENSITIES AND BIOMASSES OF PHYTOPLANKTON IN KIGGAVIK AREA LAKES, AUGUST 1989 - JAEGER LAKE

Species	Cells/L	mg/m^3	Total Biomass per Group (mg/m^3)	Percent of Total Biomass (%)
CYANOPHYTA			3.053	2.6
Gomphosphaeria lacustris v com	1,425	0.179		
Aphanocapsa delicatissima	4,275	0.504		
Oscillatoria planctonica	1,425	0.134		
Oscillatoria spa.	5,700	1.934		
Cyanarcus hamiformis	24,000	0.302		
CHLOROPHYCEAE			22.043	18.7
Elakatothrix lacustris	29,925	1.974		
Monoraphidium setiforme	24,225	0.371		
Oocystis solitaria	1,425	3.820		
Planctonema lauterbornii	5,700	5.372		
Crucigenia quadrata	1,425	0.182		
Cosmarium cf. ornatum	1,425	2.873		
Oocystis borgei	1,425	0.373		
Planctococcus alsius	2,850	1.492		
Tetraedron minimum	24,000	3.072		
Chlamydomonas 8x5 um	24,000	2.513		
CHRYSOPHYCEAE			66.636	56.4
Mallomonas pseudocoronata	1,425	0.573		
Rhizochrysis tetragena	1,425	1.289		
Dinobryon sociale	2,850	0.806		
Uroglena americana	7,125	18.672		
Dinobryon crenulatum	1,425	0.107		
Dinobryon divergens	4,275	4.477		
Mallomonas pumillo	1,425	1.492		
Dinobryon bavaricum	2,850	2.350		
Bitrichia chodatii	4,275	0.251		
Chromulina 4 um	216,000	7.238		
Ochromonas 6x5 um	216,000	16.965		
Kephryion sitta	24,000	1.005		
Dinobryon borgei	72,000	2.714		
Erkenia subaequiciliata	48,000	1.131		
Chrysidiastrum catenatum	24,000	3.142		
Chryosphyte unidentified	48,000	4.423		

TABLE 7.3: SPECIES, DENSITIES AND BIOMASSES OF PHYTOPLANKTON IN KIGGAVIK AREA LAKES, AUGUST 1989 - JAEGER LAKE

Species	Cells/L	mg/m^3	Total Biomass per Group (mg/m^3)	Percent of Total Biomass (%)
BACILLARIOPHYCEAE			11.688	9.9
Tabellaria flocculosa	2,850	4.309		
Navicula girdle	1,425	0.394		
Tabellaria fenestrata	1,425	6.270		
Fragilaria capucina	1,425	0.504		
Synedra sp.	1,425	0.212		
CRYPTOPHYCEAE			12.833	10.9
Cryptomonas erosa	1,425	2.579		
Katablepharis ovalis	120,000	7.037		
Rhodomonas minuta v nanno	96,000	3.217		
DINOPHYCEAE			1.934	1.6
Peridinium aciculiferum	1,425	1.934		
TOTAL COUNT (cells/L)	1,055,700			
TOTAL BIOMASS (mg/m^3)	118.187			

TABLE 7.4: SPECIES, DENSITIES AND BIOMASSES OF PHYTOPLANKTON IN KIGGAVIK AREA LAKES, AUGUST 1989 - POINTER LAKE

Species	Cells/L	mg/m^3	Total Biomass per Group (mg/m^3)	Percent of Total Biomass (%)
CYANOPHYTA			14.275	10.4
Aphanocapsa delicatissima	6,840	0.403		
Aphanothece spA	2,280	0.119		
Anabaena cf. planctonica	6,840	13.409		
Gloeothece linearis	2,280	0.344		
CHLOROPHYCEAE			33.158	24.1
Ankistrodesmus falcafus v spir	18,240	0.269		
Planctonema lauterbornii	25,080	8.595		
Mougeotia spl.	2,280	6.876		
Scenedesmus acutus	4,560	0.290		
Crucigenia tetrapedia	9,120	2.627		
Elakatothrix lacustris	2,280	0.086		
Monoraphidium setiforme	2,280	0.096		
Oocystis borgei	2,280	2.632		
Chrysolykos skujae	19,200	1.126		
Tetraedron minimum	9,600	0.307		
Spondylosium planum	9,600	7.680		
Planctosphaeria gelatinosa	9,600	2.574		
CHRYSOPHYCEAE			48.405	35.1
Bitrichia chodatii	2,280	0.134		
Dinobryon acuminatum	2,280	0.210		
Dinobryon bavaricum	2,280	0.537		
Chromulina 4 um	249,600	8.364		
Ochromonas 5x4 um	585,600	24.530		
Chrysophyte unidentified	4,800	0.113		
Dinobryon borgei	76,800	4.504		
Kephyrion mastigophorum	19,200	0.965		
Chrysochromulina parva	9,600	0.226		
Bicoeca cylindrica	28,800	0.679		
Pseudokephyrion planctonicum	9,600	0.754		
Ochromonas 10x7 um	28,800	7.389		

TABLE 7.4: SPECIES, DENSITIES AND BIOMASSES OF PHYTOPLANKTON IN KIGGAVIK AREA LAKES, AUGUST 1989 - POINTER LAKE

Species	Cells/L	mg/m^3	Total Biomass per Group (mg/m^3)	Percent of Total Biomass (%)
BACILLARIOPHYCEAE			5.058	3.7
Synedra sp. A.	2,280	0.403		
Synedra acus v. radians	2,280	0.552		
Tabellaria flocculosa	4,560	4.104		
CRYPTOPHYCEAE			2.654	1.9
Rhodomonas minuta v. nanno	28,800	0.965		
Katablepharis ovalis	28,800	1.689		
DINOPHYCEAE			34.167	24.8
Dymnodinium ordinatum	6,840	7.220		
Peridinium aciculiferum	4,560	11.281		
Gymnodinium uberrimum	2,280	10.830		
Gymnodinium varians	11,400	4.835		
TOTAL COUNT (cells/L)	1,243,800			
TOTAL BIOMASS (mg/m^3)	137.716			

TABLE 7.5: SPECIES, DENSITIES AND BIOMASSES OF PHYTOPLANKTON IN KIGGAVIK AREA LAKES, AUGUST 1989 - JUDGE SISSONS LAKE

Species	Cells/L	mg/m^3	Total Biomass per Group (mg/m^3)	Percent of Total Biomass (%)
CHLOROPHYCEAE			12.668	10.7
Elakatothrix gelatinosa	15,200	2.228		
Monoraphidium setiforme	26,600	1.950		
Tetraedron minimum	1,900	3.040		
Planctonema lauterbornii	1,900	0.955		
Ankistrodesmus falcatus var.	3,800	0.016		
Arthrodesmus incus	1,900	2.280		
Chlamydomonas pyrenoidosa	24,000	2.199		
CHRYSOPHYCEAE			82.555	69.6
Dinobryon borgei	15,200	0.891		
Dinobryon crenulatum	7,600	1.576		
Chrysidiastrum catenatum	1,900	1.528		
Dinobryon elegantissima	19,000	2.985		
Dinobryon bavaricum	15,200	21.918		
Pseudokephyrion attenuatum	1,900	0.287		
Salpingoeca frequentissima	3,800	0.501		
Bitrichia chodatii	1,900	0.174		
Dinobryon sociale v americana	11,400	5.909		
Dinobryon cylindricum	1,900	1.492		
Pseudokephyrion planctonicum	1,900	0.080		
Ochromonas 6x5 um	192,000	15.080		
Kephyrion littorale	48,000	2.011		
Ochromonas 10 um	24,000	12.566		
Erkenia subaequiciliata	48,000	2.011		
Chrysolykos skujae	48,000	4.398		
Chromulina 4 um	192,000	6.434		
Chrysochromulina parva	144,000	2.714		
BACILLARIOPHYCEAE			6.767	5.7
Tabellaria flocculosa	1,900	0.798		
Cyclotella sp.	1,900	5.969		

TABLE 7.5: SPECIES, DENSITIES AND BIOMASSES OF PHYTOPLANKTON IN KIGGAVIK AREA LAKES, AUGUST 1989 - JUDGE SISSONS LAKE

Species	Cells/L	mg/m^3	Total Biomass per Group (mg/m^3)	Percent of Total Biomass (%)
CRYPTOPHYCEAE			14.957	12.6
Cryptomonas marsonii	1,900	0.605		
Rhodomonas lacustris	1,900	1.685		
Rhodomonas minuta v. nanno	192,000	11.259		
Katablepharis ovalis	24,000	1.407		
DINOPHYCEAE			1.685	1.4
Peridinium inconspicum	1,900	1.685		
TOTAL COUNT (cells/L)	1,078,500			
TOTAL BIOMASS (mg/m^3)	118.633			

TABLE 7.6: DENSITIES (no./L) OF ZOOPLANKTON SPECIES SAMPLED FROM KIGGAVIK STUDY AREA LAKES IN AUGUST 1989

Species	Judge Sissons	Jaeger	Ridge	Pointer	Cirque
ROTIFERA					
Asplanchna sp.		0.0025		0.0086	
Conochilus sp.	0.201	0.0089		0.13	
Kellicottia longispina	0.241	0.293	3.235		0.217
Keratella sp.	0.0157	0.0127	0.3369	0.5044	0.0611
Lepadella ovalis		0.0025	0.0674	0.0052	0.0611
Polyarthra sp.	0.0047		1.2803		
CRUSTACEA					
Diatomus minutus	0.013		4.11		
Èpischura lacustris	0.016			0.0069	
Heterocope septentrionalis			0.135		
Calenoid copepodids	0.333		16.0		0.556
Macrocyclops fuscus	0.0094				
Cyclopoid copepodids			0.202		0.186
Nona sp.					
Bosmina coregoni	0.011				
Bosmina longirostris		0.0076		0.173	0.0611
Chydorus sphaericas	0.0063	0.039			0.647
Daphnia longiremis	0.011				0.122
Eurcerus glacialis			0.067		
Holopedium gibberum	0.0016				
CRUSTACEAN TOTALS	0.40	0.047	20.5	0.0069	1.57
GRAND TOTALS	0.864	0.366	25.43	0.18	1.91

TABLE 7.7: DENSITIES (no./L) OF ZOOPLANKTON SPECIES SAMPLED FROM POINTER LAKE IN 1979

Species	03 July	06 July	12 July	19 July	24 July	31 July	03 Aug	07 Aug	25 Aug
Calanoid copepodids	0.003	0.012	0.012	0.141	0.305	0.293	0.271	1.040	0.013
Epischura nevadensis	0	0	0	0	0.001	0.001	0.002	0.008	0.005
Diaptomus minutus	0	0	0	0	0	0	0	0	0.251
Diaptomus pribilofensis	0	0	0	0	0	0	0	0	0.005
Cyclopoid copepodids	0.012	0.064	0.024	0.006	0.001	0.002	0.001	0.015	0.007
Cyclops venustoides	0.002	0	0	0	0	0	0	0	0
Nauplii	2.382	7.892	4.018	1.071	0.153	0.012	0.010	0.030	0.0
Bosmina longirostris	0.032	0.149	0.391	0.036	0.018	0.038	0.030	0.158	0.162
Chydorus sphaericus	0.04	0.016	0.003	0.012	0.001	0.001	0.001	0.008	0.003
Daphnia longiremis	0	0.010	0.005	0.006	0.004	0.003	0.002	0.008	0.006
Holopedium gibberum	0.007	0.169	0.134	0.208	0.066	0.047	0.053	0.301	0.045
Alona guttata	0	0	0	0.004	0	0	0	0	0
TOTALS	2.442	8.312	4.586	1.484	0.549	0.397	0.370	1.568	0.497

% = percent of total sample

TABLE 7.8: DENSITIES (no./L) OF ZOOPLANKTON SPECIES SAMPLED FROM SISSONS, JAEGER AND SCOTCH LAKES, 1979

Species	Sissons Lake 10 Aug	Sissons Lake 16 Aug	Sissons Lake 24 Aug	Jaeger Lake 27 Aug	Scotch Lake 27 Aug
Calanoid copepodids	1.593	3.094	2.893	0.027	0.332
Epischura lacustris	0	0	0	0	0.042
Epischura nevadusis	0	0	0	0.006	0
Diaptomus minutus	0	0.010	0.020	1.549	0.440
Diaptomus pribilofensis	0	0		0.003	0.006
Heterocope septentrionalis	0	0	0.610	0.003	0
Cyclopoid copdpodids	2.110	2.672	4.340	0.021	0.573
Cyclops scutifer	0.301	0.241	0.151	0.003	0.090
Nauplii	0.097	0.040	0.131	0.012	2.025
Bosmina longirostris	0.118	0.060	0.412	0.518	0.301
Chydorus sphaericus	0	0	0	0.048	0.006
Daphnia longiremis	0.646	1.055	0.069	0.627	0
Daphnia pulex	0	0	0	0	0.018
Holopedium gibberum	0.409	1.195	0.593	0.054	0.006
TOTALS	5.274	8.367	9.555	2.313	4.466

those in Jaeger and Scotch Lakes once each in the 19798 ice-free season. Detailed results are presented in Table 7.6 (for 1989 data) and Tables 7.7 and 7.8 (for 1979 data). Zooplankton samples were collected by vertical haul using a 60 micron mesh Wisconsin net in 1979, and by filtering a measured volume through a 60 micron mesh plankton net at a stationary location in lake outlet streams in 1989.

Crustacean zooplankton densities in Pointer, Jaeger, Scotch and Judge Sissons Lakes in 1979 ranged between 0.4 and 9.6 organisms per litre. Densities of crustaceans varied more widely in 1989 (0.04 to 20.5 organisms per litre). Common species were Diaptomus minutus, Cyclops scutifer, Holopedium gibberum, Bosmina longirostris and Daphnia longiremis. Most of these species were also reported by Welch (1985) to occur at similar low densities in Saqvaqjuac lakes. The densities of crustacean zooplankton are low relative to other Shield lakes, reflecting the relatively low biological productivity of Kiggavik area lakes.

Rotifers were also identified in 1989 (Table 7.6), although this group was not analyzed in earlier samples. This group is commonly overlooked in aquatic biological inventories, as information on environmental factors controlling rotifer community dynamics is generally limited.

The fairy shrimp, Brachinecta sp., was observed in abundance in fishless lakes such as Sik Sik Lake and Meadow Lake during the summer months. No fairy shrimp were found in deeper lakes, providing a winter habitat for fish, probably because the shrimp are highly susceptible to fish predation.

7.3 Benthos

Benthic communities were sampled in several Kiggavik lake outlet streams in 1989 (Table 7.9) and in several Kiggavik area lakes in 1979 (Table 7.10) and 1980 (Table 7.11). Lake samples were generally collected from deep areas using a standard Ponar grab, and sieved through a 500-micron sieve. No sample replication was conducted at lake survey stations. Stream samples (1989) were collected by standard Surber sampler equipped with a 500-micron mesh collection bag. Stream samples were collected in triplicate.

TABLE 7.9a: BENTHIC MACROINVERTEBRATES IN THE THREE SURBER SAMPLES FROM THE JAEGER LAKE OUTLET STREAM, AUGUST 1989

Species	Replicate 1	2	3
P. Coelenterata			
Hydra sp.	278	1,289	578
P. Collembola sp indet.			
P. Nematoda sp. indet.	78	44	56
P. Annelida			
Cl. Oligochaeta			
F. Enchytraeidae	11	44	11
F. Naididae			
Nais simplex	67	33	22
Nais variabilis	11	122	22
F. Tubificidae			
Rhyacodrilus montana		11	
immatures with hair setae			
immatures without hair setae			
F. Lumbriculidae			
Stylodrilus heringianus	33	133	33
Cl. Arachnida			
Acarina sp. indet.	89	100	56
Cl. Insecta			
O. Coleoptera			
F. Dytiscidae			
Hydrovatus sp.			11
F. Haliplidae			
Haliplus sp.			
O. Ephemeroptera			
F. Baetidae			
Baetis sp.	11	22	22
O. Plecoptera			
F. Nemouridae			
Nemoura sp.	11	67	44
O. Diptera			
F. Chironomidae			
Chironomid pupae	44	89	89
Dicrotendipes sp.			122
Paratanytarsus sp.		11	33
Phaenopsectra sp.		22	
Polypedilum sp.			
Rheotanytarsus	333	667	67
Tanytarsus sp.		122	56
S.F. Diamesinae			
Pseudokiefferiella sp.	11	44	
S.F. Orthocladiinae			
Corynoneura sp.	100	89	56
Cricotopus sp.	111	67	78
Euryhapsis sp.	11		
Eukiefferiella sp.	67	311	
Paracricotopus sp.			
Psectrocladius sp.		67	89
Pseudosmittia sp.			
Zalutschia sp.			22
S.F. Tanypodinae			
Ablabesmyia sp.			33
Procladius sp.			
Thienemannimyia sp.	100	33	
F. Dixidae			
Dixella sp.			
F. Empididae			
Clinocera sp.			
Hemerodromia sp.			
F. Simuliidae			
Simulium sp.		11	
F. Tipulidae			
Limnophila sp.			
Prionocera sp.	44	78	167
P. Mollusca			
O. Gastropoda			
Valvata sincera helicoidea			11
Total Number of Organisms	1,411	3,522	1,678
Total Number of Taxa	18	23	22

TABLE 7.9b: BENTHIC MACROINVERTEBRATES IN THE THREE SURBER SAMPLES FROM THE RIDGE LAKE OUTLET STREAM, AUGUST 1989

Species	Replicate 1	2	3
P. Coelenterata			
Hydra sp.			11
P. Collembola sp indet.	33		11
P. Nematoda sp. Indet.	344	8,000	367
P. Annelida			
Cl. Oligochaeta			
F. Enchytraeidae	89	889	78
F. Naididae			
Nais simplex			
Nais variabilis	33	1,778	22
F. Tubificidae			
Rhyacodrilus montana			
immatures with hair setae		178	
immatures without hair setae			
F. Lumbriculidae			
Stylodrilus heringianus		178	11
Cl. Arachnida			
Acarina sp. indet.	22		33
Cl. Insecta			
O. Coleoptera			
F. Dytiscidae			
Hydrovatus sp.			
F. Haliplidae			
Haliplus sp.			
O. Ephemeroptera			
F. Baetidae			
Baetis sp.	33	178	44
O. Plecoptera			
F. Nemouridae			
Nemoura sp.	222		256
O. Diptera			
F. Chironomidae			
Chironomid pupae			11
Dicrotendipes sp.			
Paratanytarsus sp.	44		33
Phaenopsectra sp.			
Polypedilum sp.		178	
Rheotanytarsus			
Tanytarsus sp.		178	11
S.F. Diamesinae			
Pseudokiefferiella sp.			
S.F. Orthocladiinae			
Corynoneura sp.	100	356	44
Cricotopus sp.	78	356	78
Euryhapsis sp.			
Eukiefferiella sp.	89	178	33
Paracricotopus sp.			
Psectrocladius sp.	67	178	122
Pseudosmittia sp.			
Zalutschia sp.		356	
S.F. Tanypodinae			
Ablabesmyia sp.			
Procladius sp.			
Thienemannimyia sp.	33		167
F. Dixidae			
Dixella sp.			11
F. Empididae			
Clinocera sp.	22		11
Hemerodromia sp.			
F. Simuliidae			
Simulium sp.	833	1,956	1,744
F. Tipulidae			
Limnophila sp.		178	
Prionocera sp.			
P. Mollusca			
O. Gastropoda			
Valvata sincera helicoidea			
Total Number of Organisms	2,044	15,111	3,100
Total Number of Taxa	15	15	20

TABLE 7.9c: BENTHIC MACROINVERTEBRATES IN THE THREE SURBER SAMPLES FROM THE SKINNY LAKE OUTLET STREAM, AUGUST 1989

Species	Replicate 1	2	3
P. Coelenterata			
Hydra sp.	11	222	600
P. Collembola sp indet.			
P. Nematoda sp. indet.		33	44
P. Annelida			
Cl. Oligochaeta			
F. Enchytraeidae			
F. Naididae			
Nais simplex	67	478	756
Nais variabilis			22
F. Tubificidae			
Rhyacodrilus montana			11
immatures with hair setae			
immatures without hair setae			
F. Lumbriculidae			
Stylodrilus heringianus		33	
Cl. Arachnida			
Acarina sp. indet.	56	78	100
Cl. Insecta			
O. Coleoptera			
F. Dytiscidae			
Hydrovatus sp.			
F. Haliplidae			
Haliplus sp.	11		
O. Ephemeroptera			
F. Baetidae			
Baetis sp.			
O. Plecoptera			
F. Nemouridae			
Nemoura sp.	11	11	11
O. Diptera			
F. Chironomidae			
Chironomid pupae	33	67	67
Dicrotendipes sp.		11	78
Paratanytarsus sp.	33	233	533
Phaenopsectra sp.			
Polypedilum sp.			
Rheotanytarsus			
Tanytarsus sp.		11	
S.F. Diamesinae			
Pseudokiefferiella sp.			
S.F. Orthocladiinae			
Corynoneura sp.		33	33
Cricotopus sp.	67	256	333
Euryhapsis sp.			
Eukiefferiella sp.			289
Paracricotopus sp.			
Psectrocladius sp.		44	
Pseudosmittia sp.		67	110
Zalutschia sp.			
S.F. Tanypodinae			
Ablabesmyia sp.			
Procladius sp.	11		
Thienemannimyia sp.	11	11	67
F. Dixidae			
Dixella sp.			
F. Empididae			
Clinocera sp.		22	22
Hemerodromia sp.			
F. Simuliidae			
Simulium sp.			
F. Tipulidae			
Limnophila sp.			
Prionocera sp.	22	33	33
P. Mollusca			
O. Gastropoda			
Valvata sincera helicoidea			
Total Number of Organisms	333	1,644	3,111
Total Number of Taxa	11	17	17

TABLE 7.9d: BENTHIC MACROINVERTEBRATES IN THE THREE SURBER SAMPLES FROM THE POINTER LAKE OUTLET STREAM, AUGUST 1989

Species	Replicate 1	2	3
P. Coelenterata			
Hydra sp.	16,356	17,867	1,156
P. Collembola sp indet.			
P. Nematoda sp. indet.	44	1,067	1,422
P. Annelida			
Cl. Oligochaeta			
F. Enchytraeidae		311	222
F. Naididae			
Nais simplex	267	1,956	
Nais variabilis	400	9778	44
F. Tubificidae			
Rhyacodrilus montana			44
immatures with hair setae		89	44
immatures without hair setae			
F. Lumbriculidae			
Stylodrilus heringianus	89	444	44
Cl. Arachnida			
Acarina sp. indet.	178	356	133
Cl. Insecta			
O. Coleoptera			
F. Dytiscidae			
Hydrovatus sp.			
F. Haliplidae			
Haliplus sp.			
O. Ephemeroptera			
F. Baetidae			
Baetis sp.			
O. Plecoptera			
F. Nemouridae			
Nemoura sp.	178	44	89
O. Diptera			
F. Chironomidae			
Chironomid pupae	178	400	178
Dicrotendipes sp.		44	
Paratanytarsus sp.	89		133
Phaenopsectra sp.			
Polypedilum sp.			
Rheotanytarsus	1,289	133	
Tanytarsus sp.		133	311
S.F. Diamesinae			
Pseudokiefferiella sp.	444	667	89
S.F. Orthocladiinae			
Corynoneura sp.			
Cricotopus sp.		311	267
Euryhapsis sp.			
Eukiefferiella sp.	2,711	6,489	622
Paracricotopus sp.	44	622	89
Psectrocladius sp.			89
Pseudosmittia sp.			
Zalutschia sp.			
S.F. Tanypodinae			
Ablabesmyia sp.			
Procladius sp.			
Thienemannimyia sp.	133	311	622
F. Dixidae			
Dixella sp.			
F. Empididae			
Clinocera sp.			
Hemerodromia sp.			
F. Simuliidae			
Simulium sp.		44	
F. Tipulidae			
Limnophila sp.			
Prionocera sp.		222	178
P. Mollusca			
O. Gastropoda			
Valvata sincera helicoidea			-
Total Number of Organisms	22,400	32,489	5,778
Total Number of Taxa	14	20	19

TABLE 7.10: DENSITIES (no./m^2) AND DIVERSITIES OF BENTHIC INVERTEBRATES IN KIGGAVIK AREA LAKES, 1979

	Densities (no./m^2)											
	Pointer						Judge Sissons					Scotch
	PL 1	PL 2	PL 3	PL 4	PL 5	PL 6	SL A	SL C	SL D	SL H	SL I	SH I
Arthropoda												
Insecta												
Diperta												
Chironomidae												
Chorynoneura sp.	0	0	0	0	0	0	0	0	15.3	0	0	0
Orthocladius sp.	0	0	0	0	0	0	0	80.4	42.1	0	0	0
Rheocricotopus sp.	0	0	0	0	0	0	0	0	23.0	0	0	0
Cricotopus sp.	0	155.0	0	0	0	0	0	68.9	0	0	0	0
Parametriocnemus sp.	0	0	0	0	0	0	0	0	0	45.9	0	0
Psectrocladius sp.	60.3	0	0	0	60.3	25.8	0	275.6	34.4	11.5	0	45.9
Zalutchia sp.	0	0	0	0	0	0	0	0	0	0	26.8	0
sp. indet.	0	0	0	0	0	0	0	134.0	0	0	0	0
Chironomus sp.	0	0	0	0	0	103.3	0	0	2,281.0	0	0	0
Stictochironomus sp.	0	155.0	60.3	129.2	0	0	0	329.1	15.3	0	34.4	0
Dicrotendipes sp.	0	0	0	172.2	0	0	0	7.7	214.3	0	3.6	0
Gillotia sp.	0	0	0	0	43.1	0	0	0	0	0	0	0
Tanytarsus sp.	0	0	0	43.1	60.3	292.8	0	34.4	0	134.0	206.7	19.1
Cladotanytarsus sp.	0	0	198.1	0	0	0	0	72.7	0	0	0	88.0
Paratanytarsus sp.	310.0	103.3	0	0	895.6	0	0	0	275.6	0	0	0
Corynocera sp.	0	0	0	0	0	0	0	0	0	0	0	845.8
Phaenopsectra sp.	0	0	0	0	0	0	0	0	0	34.4	0	53.6
Procladius sp.	43.1	51.7	327.2	189.4	129.2	111.9	3.8	57.4	19.1	26.8	8.0	176.1
Thienemannimyia sp.	0	0	0	0	0	0	0	0	3.8	19.1	0	0
Ablabesmya sp.	0	0	0	0	0	0	0	0	0	0	0	19.1
Monodiamesa sp.	0	0	0	0	0	0	0	0	0	11.5	26.8	0
Protanypus sp.	0	0	0	0	0	0	0	0	0	11.5	0	0
Tipulidae												
Tipula sp.	0	0	8.6	0	0	0	0	7.7	23.0	0	0	0
Empididae												
Hemerodromia sp.	0	0	43.1	43.1	0	0	0	65.1	3.8	0	0	0
Coleoptera												
Zaitsevia	0	0	0	0	0	0	0	0	11.5	0	0	0
Crustacea												
Amphipoda												
Crangonyx sp.	0	0	0	0	0	0	0	3.8	0	0	11.5	0
Pelecypoda												
Pisidium sp.	180.8	172.2	0	0	473.6	0	3.8	0	0	88.0	229.6	256.4
Sphaerium sp.	0	0	0	0	0	0	0	0	0	7.7	30.6	34.4
Gastropoda												
Valvata sincera	43.1	0	0	0	68.9	0	3.8	7.7	160.7	30.6	30.6	145.4
Oligochaeta												
Lumbriculidae	0	0	120.6	17.2	68.9	0	0	302.3	252.6	11.5	15.3	107.2
Tubificidae	0	0	0	0	0	0	0	0	0	11.5	0	26.8
Immature with hair setae	0	0	0	17.2	0	0	0	53.6	0	0	0	0
Naididae	0	0	0	0	0	0	0	19.1	0	0	0	7.7
TOTAL NUMBER PER m^2	637.3	637.2	759.9	611.4	1,799.9	533.8	11.4	1,619.5	3,375.5	444.0	730.9	1,825.5
SHANNON-WEAVER DIVERSITY ($\bar{d}$)	1.87	2.22	1.64	2.36	2.07	1.62	1.59	3.20	1.80	3.09	2.65	3.29

Note: Locations of individual sampling locations within each lake are identified in the Urangesellschaft (1979) report.

TABLE 7.11: DENSITIES (no./m^2) AND DIVERSITIES OF BENTHIC INVERTEBRATES IN KIGGAVIK AREA LAKES, 1980

	Pointer			Judge Sissons			Scotch		
	PL 1	PL 3	PL 6	SL A	SL I	SL H	SCL-A	Squiggly	Kavisilik
Arthropoda									
Insecta									
Diptera									
Tipulidae									
Tipula	0	76.5	0	0	0	0	0	0	0
Empididae									
Hemerodromia	0	76.5	0	0	0	0	0	0	0
Chironomidae									
Chironomus sp.	0	0	0	0	0	0	191.4	191.4	0
C. salinarius	0	0	0	0	0	0	0	76.5	0
Stictochironomus sp.	0	0	0	0	57.4	0	0	0	0
Endochironomus sp.	0	0	0	0	0	0	459.2	0	0
Chorynocera sp.	0	0	172.2	0	9,950		4,630	0	0
Tanytarsus sp.	0	0	0	0	0	172.2	0	267.9	134.0
Cladatanytarsus sp.	133.9	0	0	0	0	0	0	0	0
Procladius sp.	0	0	95.7	0	57.4		38.3	574.0	95.7
Psectrocladius	0	0	19.1	0	0	57.4	191.4	38.3	0
Eukiefferiella sp.	0	0	0	0	0		0	38.3	0
Protanypus sp.	57.4	0	38.7	0	0	0	0	0	0
Pagastia sp.	0	0	0	0	0	19.1	0	0	0
Monodiamesa	0	0	38.3	0	0	0	0	0	0
Mollusca									
Bivalvia									
Pisidium sp.	19.1	0	822.8	0	344.4	306.1	1,900	918.5	0
Gastropoda									
Valvata sincera	0	0	76.5	0	0	95.1	1,416	0	0
Annelida									
Oligochaeta									
Ilyodrilus templetoni	0	0	0	0	0	0	229.6	0	0
Immature capilliform	19.1	0	0	0	0	0	1,071	0	0
Pristina sp.	38.3	114.8	0	0	0	0	0	0	0
Lumbriculidae	38.3	803.7	287.0	0	229.6	0	1,071	0	114.6
TOTAL (no./m^2)	459.2	1,071.6	1,550	0	10,639	650.6	11,289	2,105	344.4
SHANNON-WEAVER DIVERSITY ($\bar{d}$)	2.41	1.20	2.10	0	0.45	1.89	2.53	2.12	1.58

Note: Locations of individual sampling locations within each lake are identified in the Urangesellschaft (1979) report.

Benthic communities in Kiggavik area lakes are typically low in number and dominated by various chironomids (midge flies) and the pea clam, Pisidium. Benthic communities in Arctic lakes are typically dominated by chironomids, including Saqvaqjuac lakes and high Arctic lakes (Welch, 1985). Other benthic fauna, found in the stomachs of fish taken in the 1986 netting program include stoneflies, caddisflies and amphipods. In general, densities of benthic organisms in Kiggavik area lakes are similar to densities reported in ELA Shield lakes in northwestern Ontario (Hamilton, 1971).

Stream benthic communities (Table 7.9) include an assemblage of various groups. Many of the stream-dwelling species are adapted to feeding on organisms drifting downstream from lakes, and include black flies (Simulium) and Hydra. As in the lakes, however, chironomids tend to be the most common and diverse group of organisms in the outlet streams, although Hydra and nematodes were dominant in some samples. Benthic stream communities may provide a useful biomonitoring tool to evaluate any effects of site development on aquatic systems. Variation among replicates at individual survey stations is reasonably large, indicating that variance must be accounted for in any benthic monitoring program at the Kiggavik project site.

7.4 Fish

7.4.1 Community Characteristics

Based on the general geomorphology of the study area, lakes can be classified into one of three general categories:

1. **Escarpment Headwater Lakes** are relatively small but deep (greater than 2 m mean depth), and occur along the rock escarpment traversing the northern end of the study area. These lakes are extreme headwaters which occur at the highest elevations within the study area.
2. **Tundra Plain Lakes** are considerably larger than the escarpment lakes, but are comparatively shallow (mean depth between 1 m and 2 m). These lakes occur along the flat plain between the rock escarpment to the north and Judge Sisson's Lake to the south.
3. **Regional Mainstream Lakes** are relatively large and deep, and the primary receiving waters of localized headwater drainages. Within the study area,

this includes Judge Sisson's Lake, which receives most study area discharge, and Skinny Lake/Kavisilik Lake to the northeast of the study area which is part of another branch of the Anigaq River.

Key habitat features of study area lakes are presented in a map appendix located at the back of this document. These show the bathymetry and other physical characteristics of each lake basin, and resident fish species. The location of each of these lakes within the study area is shown in Figure 3.2.

Mean and maximum water depths are critical criteria for fish populations. Lakes in the study area with a mean depth of less than 1 m tend to be fishless, probably due to winter habitat limitations. Ice cover tends to be about 2 m thick on most lakes, so lakes such as Meadow Lake and Sik Sik Lake, which contain no fish, are sufficiently shallow to freeze to the bottom. Lakes in the area with a mean depth of 1 m to 2 m contain fish, but in generally low numbers compared with the deeper lakes.

Those lakes with mean depths greater than 2 m tend to provide the best habitat conditions for fish. In these lakes, both species diversity and relative abundance are considerably greater than in shallow lakes. Both the small escarpment headwater lakes (Ridge, Cirque, Felsenmeer and Escarpment) and the large regional mainstream lakes (Judge Sisson's and Skinny Lake/Kavisilik Lake) provide good fish habitats and so support the largest and most diverse fish populations in the area.

Species Distribution and Relative Abundance in the Study Area

Fish populations in selected study area lakes were sampled in 1979, 1980 and 1986 by means of index monofilament gill nets with six stretch mesh sizes ranging from 3.8 cm to 12.7 cm. This allowed for the collection of representative samples of various fish species and age classes in a standardized sampling methodology which allowed for direct comparison of results between the different lakes. A few fish were also collected by gill net from Pointer Lake in 1988 for analysis of baseline concentrations of metals and radionuclides.

The distribution and relative abundance of major fish species (listed in Table 7.12) in study area lakes are provided in Table 7.13. The four major species (lake trout, Arctic

TABLE 7.12: FISH SPECIES IN THE STUDY AREA

Common Name	Scientific Name
Lake trout	Salvelinus namaycush
Cisco	Coregonis artedii
Round whitefish	Prosopium cylindraceum
Arctic grayling	Thymallus arcticus
Burbot	Lota lota
Ninespine stickleback	Pungitius pungititius
Sculpin	Cottus sp.

TABLE 7.13: DISTRIBUTION AND RELATIVE ABUNDANCE OF MAJOR FISH SPECIES IN STUDY AREA LAKES

Lake	Lake Trout	Arctic Grayling	Round Whitefish	Cisco	Arctic Char
Escarpment	A	C	A	-	-
Felsemeer	A	A	A	-	-
Meadow	-	-	-	-	-
Ridge	A	-	-	-	-
Cirque	-	A	-	-	-
Drum	-	A	-	-	-
Lin	-	A	-	-	-
Sik Sik	-	-	-	-	-
Caribou	S	C	-	-	-
Willow	C	C	-	-	-
Sissons	A	S	C	C	-
Pointer	S	S	-	C	-
Scotch	A	-	A	-	-
Skinny	A	S	A	C	-
Kavisilik	A	S	C	A	-
Squiggly	A	S	A	-	C

A = Abundant
C = Common
S = Scarce

grayling, round whitefish and cisco) are broadly distributed within the study area, where habitats are suitable, and are typical of the fish fauna found in similar Arctic environments.

Lake Trout

Lake trout are the most abundant species in most lakes where the habitat is favourable to it. This species is also the major predator at the top of aquatic food chains in study area lakes, and so is the dominant species in Escarpment, Felsenmeer, Ridge, Sisson's, Scotch, Skinny, Kavisilik and Squiggly Lakes. In the small escarpment lakes (Felsenmeer, Ridge and Escarpment), lake trout have survived in small isolated populations since the last glaciation, with no possibility of recruitment from other lakes.

In many of the tundra plain lakes (Caribou, Drum, Lin, Willow, Pointer), lake trout are absent or exist in very sparse populations, probably due to severe habitat stress during the winter when most of the water in these lakes would freeze. There is some possibility of trout movement between some of these lakes during the short open-water season, possibly providing for limited recolonization by this species after exceptionally severe winterkills. Scotch Lake, because of its greater depth, contains a large and more stable lake trout population, judging by the multi year-class structure of the population.

Lake trout populations in the large mainstream lakes appear comparatively large and robust, with a broad range of age classes. Age-size characteristics for lake trout were documented from the results of extensive experimental netting carried out in 1979, using otoliths for age determination. The data are presented in Table 7.14 and Figure 7.1. The length (L)-weight (W) relationship for Kiggavik area lake trout, based on the 1979 data, is $\log_{10}W = -5.199 + 3.084 \log_{10}L$ ($r^2 = 0.97$). Mean condition factors, based on weight-length measurements, are presented in Table 7.15 for all age classes sampled.

The levels of female sexual maturity, using Nikolsky's (1963) designations, are listed in Table 7.16. The first individuals to show signs of previous spawning activity were in the 13-year age class. In comparison, Moshenko et al. (1978) reported that the onset of sexual maturity is 15 to 16 years in Great Bear Lake and 8 to 12 years in Great Slave Lake. Lake trout in Kiggavik area lakes probably do not spawn each year, but more likely spawn every two years, as reported in other northern populations (Scott and Crossman, 1973; Moshenko et al., 1978).

TABLE 7.14: MEAN FORK LENGTHS (mm) AND WEIGHTS (g) OF LAKE TROUT IN ALL AGE CLASSES SAMPLED FROM POINTER AND SISSONS LAKES

Age Class	No. of Fish	Mean Length (mm)	Standard Deviation	Mean Weight (g)	Standard Deviation
5	2	227.5	38.9	142.5	45.9
7	1	265.0	-	175.0	-
8	4	345.0	23.5	381.3	122.4
9	12	346.3	48.8	481.9	235.6
10	9	365.9	57.6	573.9	297.2
11	6	364.8	57.1	530.0	340.2
12	3	454.0	45.2	1,010.0	371.6
13	6	512.0	36.9	1,421.7	333.8
14	9	565.9	108.2	1,983.3	938.5
15	12	541.9	65.8	1,816.7	656.1
16	4	603.3	69.0	2,670.0	825.0
17	5	596.0	36.0	2,500.0	387.3
18	18	562.6	64.2	1,906.1	686.8
19	11	606.4	39.7	2,430.0	451.9
20	11	623.6	60.4	2,850.0	793.7
21	4	648.8	37.3	2,950.0	526.0
22	5	656.6	41.7	3,270.0	717.3
23	10	698.7	85.8	4,030.0	1,944.8
24	9	664.3	81.8	3,634.4	1,438.1
25	4	673.0	112.1	3,612.5	1,946.1
26	4	640.5	68.5	3,000.0	912.9
27	3	704.3	33.0	3,866.7	665.8
28	5	708.0	48.8	4,300.0	940.7
29	3	643.3	12.6	3,000.0	-
30	3	691.0	76.9	3,950.0	1,344.4
31	3	674.0	80.5	3,350.0	1,310.5
32	1	705.0	-	5,700.0	-
33	4	763.8	56.2	5,350.0	1,171.2
34	3	826.7	69.0	6,833.3	2,478.6
35	3	829.0	18.5	6,400.0	600.0
36	2	650.0	77.8	3,225.0	671.8
37	1	735.0	-	6,000.0	-
38	1	775.0	-	5,000.0	-
39	3	808.0	90.1	6,100.0	2,946.2
40	2	737.5	38.9	4,850.0	636.4
41	1	756.0	-	4,500.0	-

FIGURE 7.1
Growth Curve and Equation for Lake Trout Sampled from Pointer and Sisson's Lake (1979)

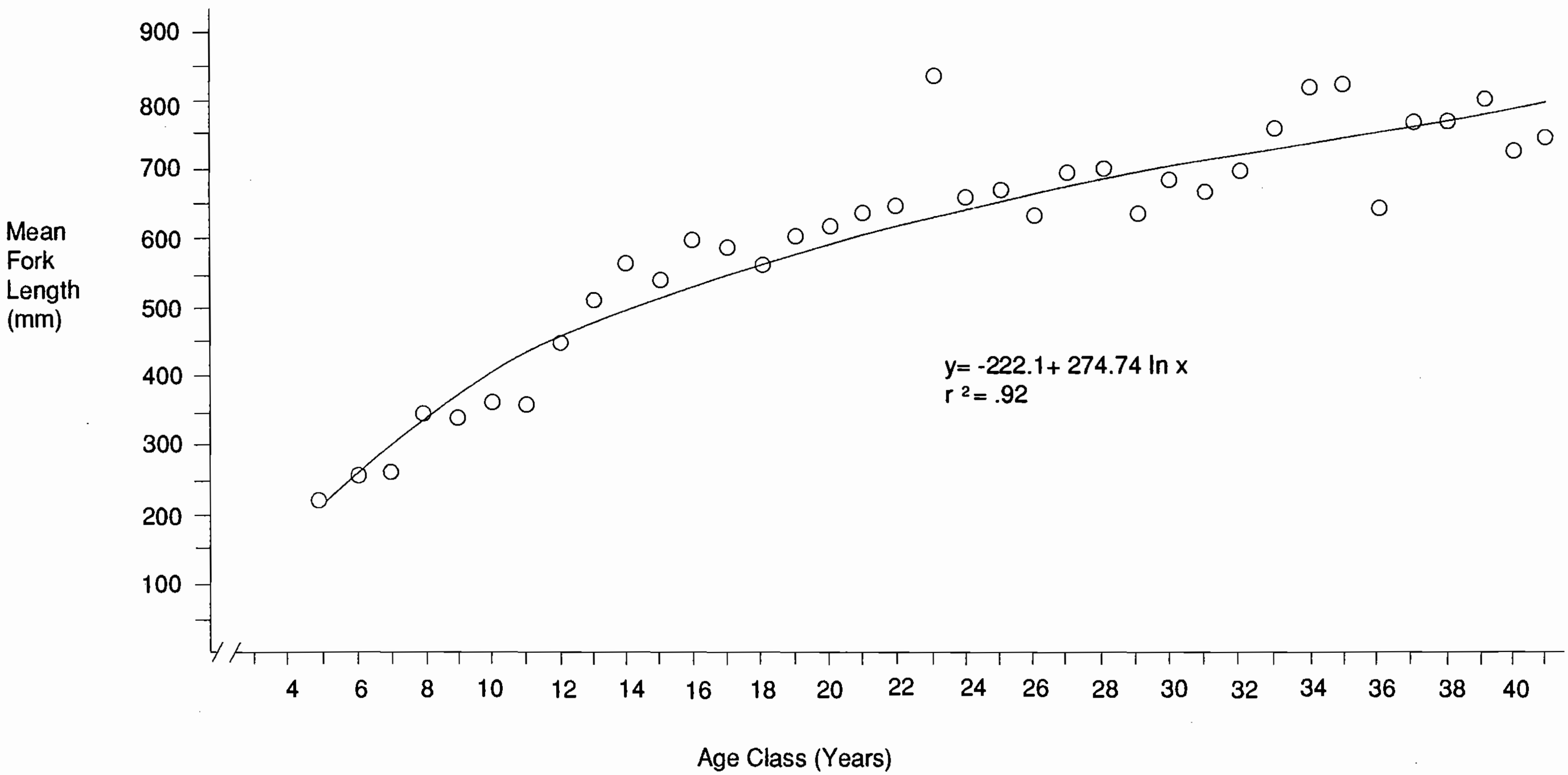


TABLE 7.15: MEAN CONDITION FACTORS ($10^5W/L^3$) FOR ALL AGE CLASSES OF LAKE TROUT COLLECTED FROM POINTER AND SISSONS LAKES (based on 1979 data)

Age Class	Mean Condition Factor	No. of Fish Measured	Standard Deviation
5	1.22	2	0.23
7	0.94	1	-
8	0.90	4	0.17
9	1.07	12	0.11
10	1.08	9	0.08
11	0.99	6	0.09
12	1.04	3	0.10
13	1.04	6	0.05
14	1.07	9	0.16
15	1.09	12	0.12
16	1.19	4	0.12
17	1.18	5	0.09
18	1.03	18	0.15
19	1.10	11	0.14
20	1.15	11	0.09
21	1.07	4	0.05
22	1.13	5	0.08
23	1.15	10	0.16
24	1.16	9	0.25
25	1.12	4	0.06
26	1.12	4	0.07
27	1.11	3	0.23
28	1.21	5	0.17
29	1.13	3	0.07
30	1.18	3	0.17
31	1.07	3	0.24
32	1.03	1	-
33	1.19	4	0.04
34	1.17	3	0.16
35	1.12	3	0.10
36	1.19	2	0.18
37	1.51	1	-
38	1.07	1	-
39	1.11	3	0.25
40	1.21	2	0.04
41	1.04	1	-

TABLE 7.16: LEVELS OF SEXUAL MATURITY IN EACH AGE CLASS OF FEMALE LAKE TROUT COLLECTED FROM POINTER AND SISSONS LAKES, 1979 (after Nikolsky, 1963)

Age Class	Immature	Resting Stage	Maturation, Maturity, Reproduction	Spent Condition	Undetermined
5	1				1
8	2				1
9	7				1
10	2				
11	2				
12	1				
13		3			
14	1	3			
15		4	2		
16		1			
17		3			
18		8			
29		6	1		1
20		4	4		1
21		4			
22		1			
23		5	3		1
24		3	1		1
25					1
26		1	1		
27		2			
28		1	1		
29		2			
31		2			
33		1	1		
34		1			
35			1		
38			1		
39		2	1		
40		1			

Arctic Grayling

Arctic grayling are the dominant species in all stream habitats of sufficient flow to support it within the study area and in several lakes where it is the only major fish species present. In Lin and Cirque Lakes, this species reaches a high abundance of small stunted fish because of the absence of lake trout or other predatory or competing species. In most other lakes, where lake trout, round whitefish or cisco are present, the grayling population is more sparse, but appears to consist of individuals of a larger average size. Grayling are very abundant in stream sections linking most of the tundra plain lakes, particularly below Pointer Lake.

Round Whitefish

Round whitefish are most commonly found in the larger and deeper mainstream lakes of the study area, but also occur as isolated populations in Escarpment and Felsenmeer Lakes. This species is generally absent from the shallower lakes in the study area.

Cisco

Like the round whitefish, cisco prefer the larger and deeper lakes and were found only in the mainstream lakes. An exception is Pointer Lake where several cisco were collected.

Arctic Char

Arctic char were not found in any study area lakes within the Aniguq watershed due to the restricted access of this species up the Aniguq River. This species was found in Squiggly Lake within the Thelon drainage to the northwest of the study area.

Fish Biomass, Standing Stock and Sustainable Yield

Although the fish sampling techniques used in this study were not intended to yield absolute measurements of fish stocks or production, both of which would require intensive sampling, the direct comparability of the index netting data allows for a comparative assessment of fish biomass and standing stocks between lakes. This is provided in Table 7.17 for the 1986 data. Unfortunately, catches cannot be readily

TABLE 7.17: STANDARDIZED CATCH PER UNIT EFFORT* FOR FISH STOCKS IN STUDY AREA LAKES

Lake	Species	Number	Biomass (kg) Total	Biomass (kg) Mean	Total Biomass of All Species (kg)
Ridge	Lake Trout	17	26.5	1.6	26.5
Escarpment	Lake Trout	8	13.4	1.7	
	Grayling	4	1.4	0.4	
	Round Whitefish	26	13.2	0.5	28.0
Felsemeer	Lake Trout	8	13.2	1.7	
	Grayling	8	4.2	0.5	
	Round Whitefish	7	2.3	0.3	19.7
Skinny	Lake Trout	9	27.6	3.1	
	Round Whitefish	8	3.4	0.4	
	Cisco	1	0.5	0.5	31.5
Kavisilik	Lake Trout	11.3	36.6	3.2	
	Cisco	10.0	2.4	0.2	
	Round Whitefish	1.0	0.3	0.3	39.3
Lin	Grayling	62	13.3	0.2	13.3
Cirque	Grayling	11	2.6	0.2	2.6
Caribou	Lake Trout	1	1.2	1.2	
	Grayling	4	1.0	0.3	2.2
Pointer	Lake Trout	2	7.2	3.6	
	Cisco	6	1.1	0.2	
	Grayling	1	0.3	0.3	4.1
Sissons	Lake Trout	9.8	26.5	2.7	
	Cisco	1.7	0.5	0.3	
	Round Whitefish	1.4	0.5	0.4	
	Grayling	0.3	0.2	0.6	
	Burbot	0.2	0.1	0.5	27.8
Scotch	Lake Trout	11.0	24.3	2.2	
	Round Whitefish	7.3	4.6	0.6	28.9

* One standard unit of effort represents an 18-hour set of index monafilament gill nets of 45.7 m (150 feet) total length, consisting of 7.6 m (25 feet) panels of the following stretch mesh sizes: 3.8 cm (1.5 inch), 5.1 cm (2 inch), 6.4 cm (2.5 inch), 7.6 cm (3 inch), 10.2 cm (4 inch) and 12.7 cm (5 inch).

compared among years, as sampling methods (effort) varied between surveys. Furthermore, the focus of sampling efforts in 1986 was on lakes not sampled previously, in order to provide a broader picture of fish communities in the study area.

In comparing the total biomass of all fish species collected, it becomes apparent that the deeper lakes, which provide a secure wintering habitat, contain the largest fish biomass (or standing stock of fish) per unit area, regardless of size. The large mainstream lakes had biomass yields of 27.8 to 39.3 kg of fish per unit of sampling effort, while Ridge, Felsenmeer and Escarpment Lakes, much smaller in size, had yields of 20 to 28 kg of fish per unit. Ridge Lake is noteable in that all of this biomass consists of lake trout, while the other lakes contain a more diverse fish population.

The shallow tundra plain lakes contain more sparse fish populations with total biomass yields ranging from 2 to 13 kg per unit of sampling effort. This reflects the less suitable fish habitats, particularly during the winter, in these lakes.

The numbers of fish of each species caught per unit of sampling effort, as well as the total and mean biomass for each species in each lake, are also provided in Table 7.17. This allows for a direct comparison of numerical abundance of each species between and within lakes and a comparison of the average size (weight) of fish between lakes. For instance, lake trout were most abundant per unit of sampling effort in Ridge Lake (17 fish per unit) and least abundant in Caribou Lake (1 fish per unit). Although abundant in Ridge Lake, lake trout are of a much smaller average size here (1.6 kg mean weight) compared to Skinny Lake (3.1 kg mean weight) or Judge Sisson's Lake (2.7 kg mean weight). This likely reflects a stunting of the lake trout in Ridge Lake, where forage fish species are absent, compared to the larger lakes where lake trout can feed on round whitefish and cisco. Similar comparisons can be made between various other lakes and species.

One must not assume that comparison of biomass statistics relating to the sampling program is an indication of the levels of fish production in these lakes. The physical and age characteristics of fish populations, particularly the lake trout, suggest very slow-growing, low productive populations. These will have characteristically high natural standing stocks of fish in the more suitable lakes, but would have very low rates of replacement. This is typical of most Arctic lakes. The situation likely reaches an

TABLE 7.18: LAKE CHARACTERISTICS AND FISH YIELDS, BASED ON THE MORPHOEDAPHIC INDEX, IN KIGGAVIK AREA LAKES

	Lake Area (ha)	Mean Depth (m)	TDS[1] (mg/L)	MEI[2] (ppm/m)	Yield (kg/yr)
Escarpment	12.7	2.2	9	4.1	13
Felsenmeer	20.8	2.0	34	17	21
Ridge	16.7	2.3	7	3.0	17
Cirque	5.6	2.6	13	5.0	6
Crash	8.1	1.1	(15)	14	8
Drum	25	1.3	(30)	23	25
Lin	48	1.3	30	23	48
Fox	128	1.7	(33)	19	130
Caribou	341	1.4	33	24	340
Willow	54.9	1.4	(28)	20	55
Pointer	374	1.5	28	19	370
Scotch	195	3.6	13	3.6	200
Jaeger	281	1.6	20	13	280
Judge Sissons	9,550	4.6	33	7.2	9,600
Skinny	197	3.1	6	1.9	200
Kavisilik	564	4.2	(6)	1.4	560
Squiggly	638	6.0	(20)	3.3	640

[1] TDS = Total dissolved solids. Assumed values are in parentheses.

[2] MEI = Morphoedaphic index (TDS (ppm)/mean depth (m)).

ABLE 7.19: CONCENTRATIONS OF TRACE METALS IN POINTER LAKE GRAYLING AND LAKE TROUT, JULY 1988, AND BAKER LAKE ARCTIC CHAR (AUGUST 1989) (ug/g fresh weight of boneless, skinless fillets)

	Fish Characteristics			Metal					
).	Fish Length (mm)	Weight (g)	Sex	Cd	Pb	Ni	Hg	As	Se
ayling									
	318	375	M	L 0.01	L 0.1	0.2	0.04	L 0.2	0.2
	305	325	M	L 0.01	L 0.1	0.1	0.06	L 0.2	0.2
	298	325	M	0.01	0.1	0.2	0.08	L 0.2	0.2
	311	350	M	L 0.01	L 0.1	0.3	0.08	L 0.2	0.2
	311	350	M	L 0.01	L 0.1	L 0.1	0.06	L 0.2	L 0.2
	318	400	M	L 0.01	L 0.1/L 0.1	L 0.1/L 0.1	0.08/0.10	L 0.2/L 0.2	0.2/0.2
	321	380	M	L 0.01	L 0.1	L 0.1	0.14	L 0.2	0.2
	298	330	M	0.06	1.0	0.3	0.14	L 0.2	0.2
	356	475	F	L 0.01	L 0.1	0.4	0.18	L 0.2	0.2
	286	310	F	L 0.1	L 0.1	0.2	0.08	L 0.2	0.2
ike Trout									
	724	4,800	M	L 0.01	L 0.1	L 0.1	1.02	L 0.2	0.2
	527	1,600	F	L 0.01	L 0.1/L 0.2	0.1/L 0.2	0.60/0.54	L 0.2/L 0.2	0.2/0.2
	597	2,300	F	L 0.01	0.1	0.1	0.44	L 0.2	0.2
rctic Char									
A	-	-	-	L 0.01	0.05	L 0.2	0.5	1.4	1.80
B	-	-	-	L 0.01	0.10	L 0.2	0.5	8.0	1.80

Notes: L = less than.
Fish numbers for grayling and lake trout correspond to numbers listed in Table 7.13.
Arctic char A and B composite of three fish each.

extreme in the small headwater lakes where all of the fish biomass is tied up in a relatively small population of old, slow-growing fish.

The maximum sustainable fish harvest in Kiggavik area lakes may be estimated using the morphoedaphic index (MEI). The MEI is calculated as the total dissolved solids concentration divided by the mean water depth, and is listed for Kiggavik area lakes in Table 7.18. Based on information provided in Schlesinger and Regier (1982), the annual yield of fish in subarctic lakes, with MEI values in the range seen in the Kiggavik area (1.4 to 24), is in the range of approximately 1 to 1.1 kg/ha/yr. That is, the fish populations in Kiggavik area lakes could sustain a long-term harvest of about 1 kg/ha each year, based on all species, or somewhat less for individual species, without resulting in a serious collapse in a stock. These yields are only about 10 to 20% of yields that can be typically sustained in southern Canadian lakes.

Many of the smaller Kiggavik area lakes, such as Escarpment, Felsenmeer, Ridge, Cirque, Drum and Lin, have very low sustainable yields (6 to 48 kg/yr), while most of the larger lakes, including Pointer, Jaeger and Skinny, could sustain annual harvests of 200 kg or more (Table 7.18). Judge Sisson's Lake, which is the largest lake studied, could sustain an annual harvest of up to 9.6 tonnes of fish, and as such represents a larger fishery resource than the combined resources of all other Kiggavik area lakes that were studied.

7.4.2 Tissue Metal and Radionuclide Levels

Baseline concentrations of trace metals in fish from Pointer Lake are low and, except for nickel and mercury, are generally below the analytical detection limits in muscle tissue (Tables 7.19 and 7.20). Mercury concentrations tend to be higher in larger fish than in smaller fish.

Radionuclide levels in composite samples of fish muscle and fish bone also tend to be below analytical detection limits (Table 7.20). The most notable exception to this is the occurrence of measurable concentrations of Ra-226 in grayling bone in 1988, reflecting the bone-seeking properties of radium in fish (Wait et al., 1988). For unknown reasons, detectable concentrations of Ra-226 were reported in fish muscle in 1980, but not in subsequent studies.

TABLE 7.20: CONCENTRATIONS AND ACTIVITIES OF U-238 AND TH-232 DECAY CHAIN RADIONUCLIDES IN FISH FROM KIGGAVIK AREA LAKES[1]

Lake	Species/Tissue	U (ug/g)	Th-230 (Bq/g)	Ra-226 (Bq/g)	Pb-210 (Bq/g)	Po-210 (Bq/g)	Th-232 (Bq/g)	Ra-228 (Bq/g)	Th-228 (Bq/g)
July 1988									
Pointer[2] Lake	Grayling Composite 1-5	L 0.2	L 0.005	L 0.005	L 0.02	L 0.005	L 0.005	L 0.1	L 0.005
	Grayling Composite 6-10	L 0.2	L 0.005	L 0.005	L 0.02	L 0.005	L 0.005	L 0.1	L 0.005
	Lake Trout Composite 11-13	L 0.2	L 0.005	L 0.005	L 0.02	L 0.005	L 0.005	L 0.1	L 0.005
	Grayling Bone Composite 1-5	L 0.2	L 0.005	0.017±0.005	L 0.02	L 0.005	L 0.005	L 0.1	L 0.005
	Grayling Bone Composite 6-10	L 0.2	L 0.005	0.015±0.005	L 0.02	0.007±0.005	L 0.005	L 0.1	L 0.005
July 1986									
Ridge Lake	Lake Trout Composite	L 0.5	L 0.001	L 0.001	L 0.001	L 0.001	L 0.002	-	-
Caribou Lake	Lake Trout Composite	L 0.5	L 0.001	L 0.001	L 0.001	L 0.001	L 0.002	-	-
	Grayling Composite	L 0.5	L 0.001	L 0.001	L 0.001	L 0.001	L 0.002	-	-
Willow Lake	Lake Trout Composite	L 0.5	L 0.001	L 0.001	L 0.001	L 0.001	L 0.002	-	-
	Grayling Composite	L 0.5	L 0.001	L 0.001	L 0.001	L 0.001	L 0.002	-	-
Lin Lake	Grayling Composite	L 0.5	L 0.001	L 0.001	L 0.001	L 0.001	L 0.002	-	-
Felsenmeer Lake	Lake Trout Composite	L 0.5	L 0.001	L 0.001	L 0.001	L 0.001	L 0.002		
	Grayling Composite	L 0.5	L 0.001	L 0.001	L 0.001	L 0.001	L 0.002		
Summer 1980									
Sissons Lake	Lake Trout	L 0.2	L 0.008	0.013	L 0.01	-	L 0.0012	-	-
		L 0.2	L 0.008	0.005	L 0.01	-	L 0.0012	-	-
		L 0.2	L 0.008	0.003	0.02	-	L 0.0012	-	-
		L 0.2	L 0.008	0.003	L 0.01	-	L 0.0012	-	-
		L 0.2	L 0.008	0.005	L 0.01	-	L 0.0012	-	-
		L 0.2	L 0.008	0.003	L 0.01	-	L 0.0012	-	-
		L 0.2	L 0.008	0.005	L 0.01	-	L 0.0012	-	-

[1] All samples from skinless, boneless fillets unless indicated otherwise.

[2] Composites of tissues from fish as numbered in Table 7.12.

7.5 Monitoring Implications

Biomonitoring is a useful means of measuring the effects of mining development on the aquatic environment, although certain components are perhaps more valuable than others.

Phytoplankton communities are highly variable in terms of biomass and species composition from lake to lake and season to season. In the face of this variability, it will be difficult to effectively monitor phytoplankton in a manner that permits the detection of response to mining activities. Zooplankton communities may be expected to show similar variation and be of very limited use in biomonitoring. Nonetheless, it may be prudent to occasionally monitor the plankton communities downstream of project activities simply to permit the detection of any gross changes and to demonstrate the overall health of the aquatic ecosystem.

Benthic communities have been widely used to monitor the effects of industrial effluents on aquatic ecosystems, and are generally less variable than plankton communities. Because the outlet stream of Pointer Lake will receive process effluents, and because the Skinny Lake outlet may be dewatered to some extent on a seasonal basis, the benthic communities of stream systems in the project area will provide a useful indicator of the biological effects of these consequences of site development.

Fish communities are of prime importance, as they represent a food source and an economic resource to man. Because project activities are projected to affect water quality in Judge Sissons Lake and water levels in Skinny Lake, the structure of these fish communities should be monitored to assess project effects. Tissue concentrations of radionuclides and metals should also be measured downstream of effluent releases, particularly in Judge Sissons Lake and perhaps downstream in the Aniguq system.

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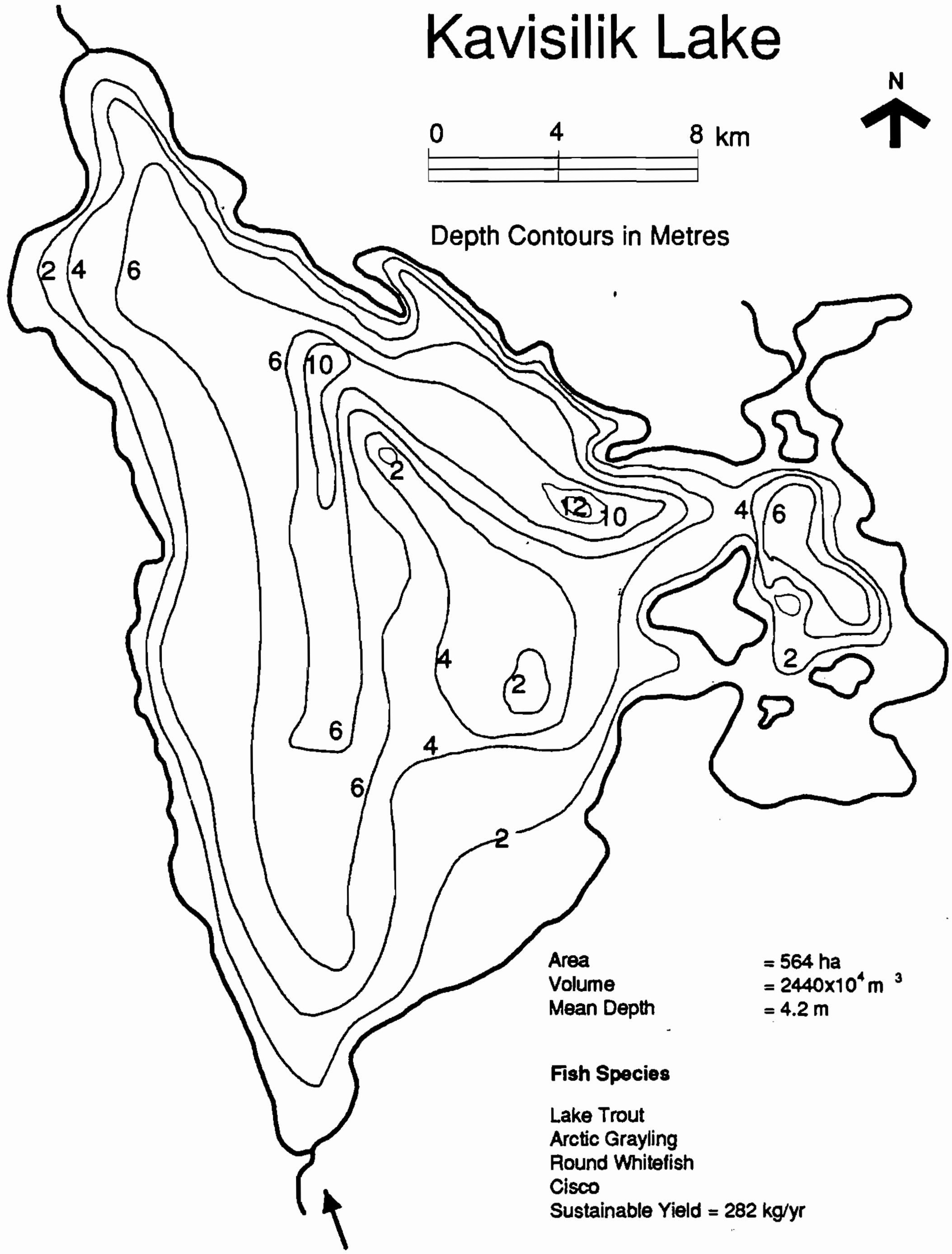
APPENDIX 1

Map Bathymetries

Kavisilik Lake

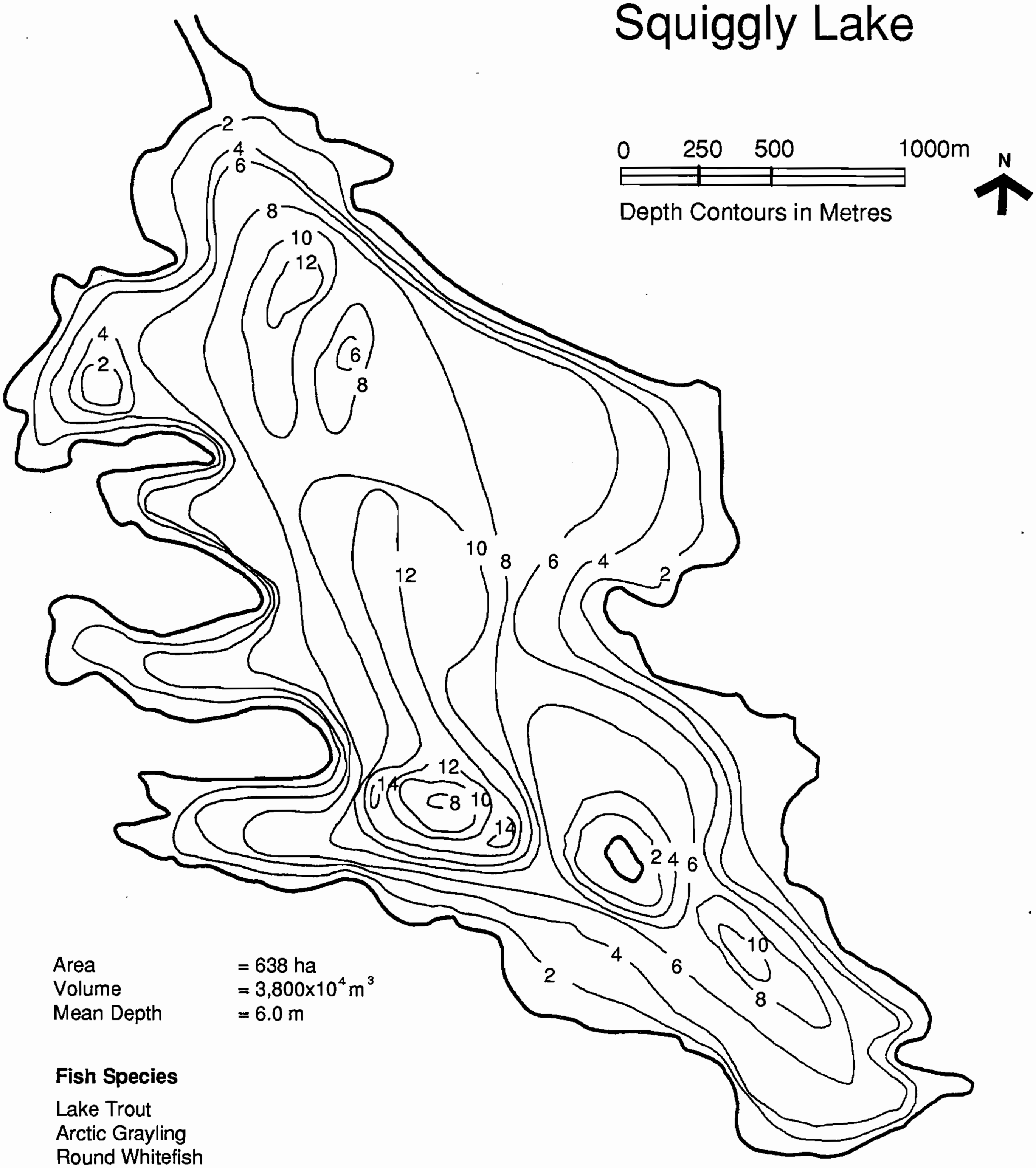


Area = 564 ha
Volume = $2440x10^4 m^3$
Mean Depth = 4.2 m

Fish Species

Lake Trout
Arctic Grayling
Round Whitefish
Cisco
Sustainable Yield = 282 kg/yr

Squiggly Lake

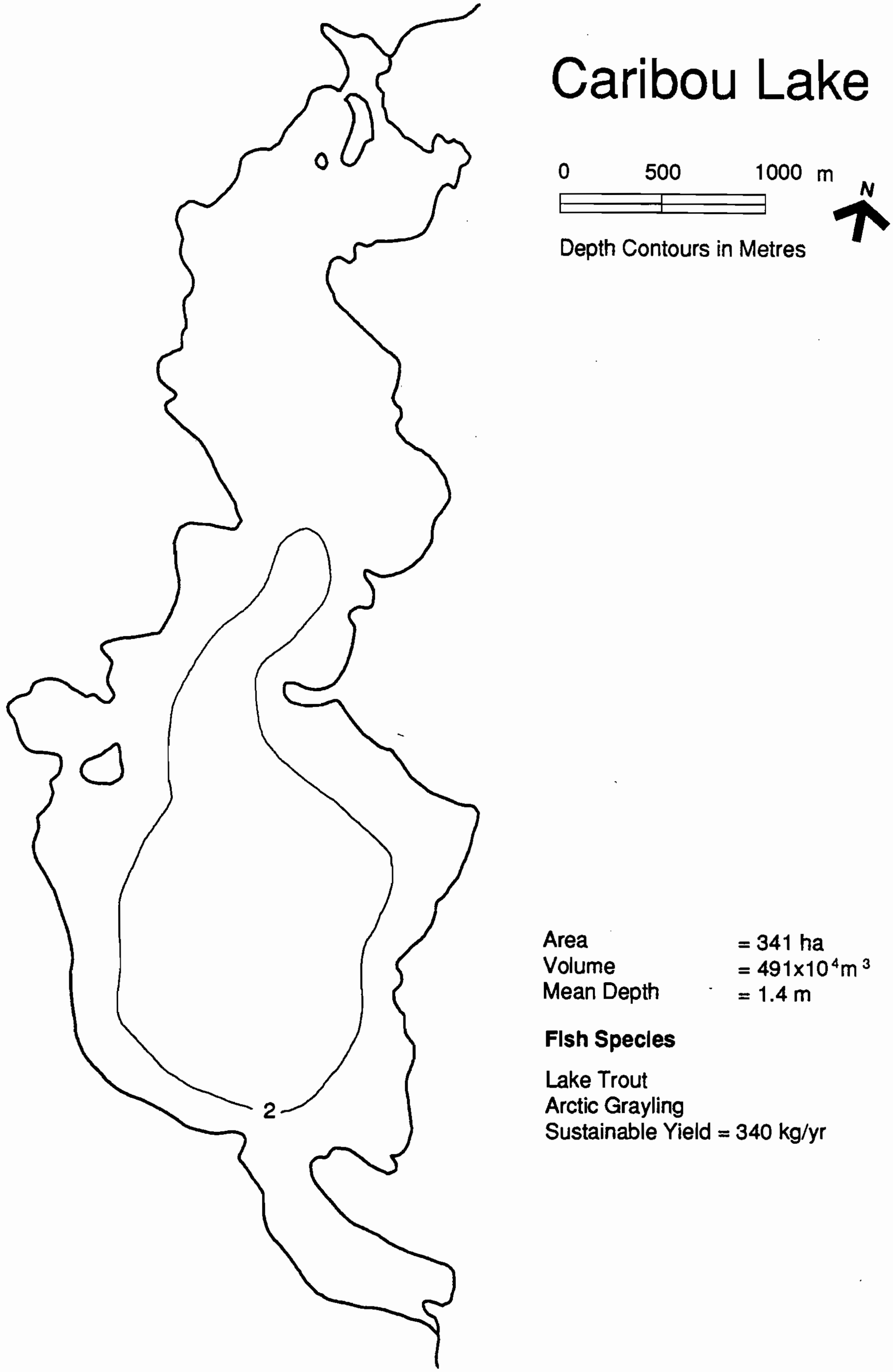


Area = 638 ha
Volume = $3,800 \times 10^4 m^3$
Mean Depth = 6.0 m

Fish Species

Lake Trout
Arctic Grayling
Round Whitefish
Arctic Char
Sustainable Yield = 640 kg/yr

Caribou Lake



Area = 341 ha
Volume = $491 \times 10^4 m^3$
Mean Depth = 1.4 m

Fish Species

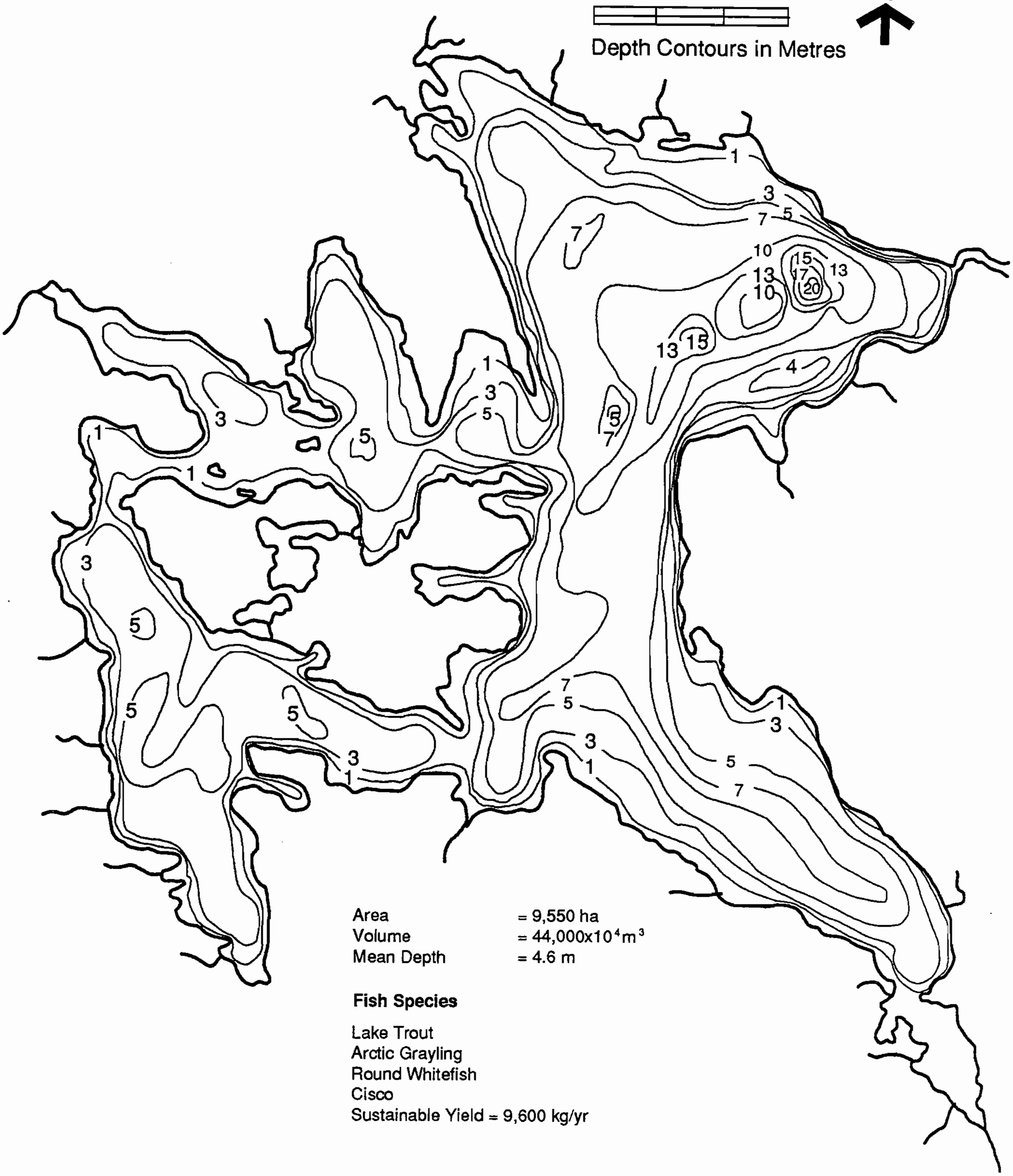
Lake Trout
Arctic Grayling
Sustainable Yield = 340 kg/yr

Judge Sisson's Lake

0 1 2 3 Km

N

Depth Contours in Metres

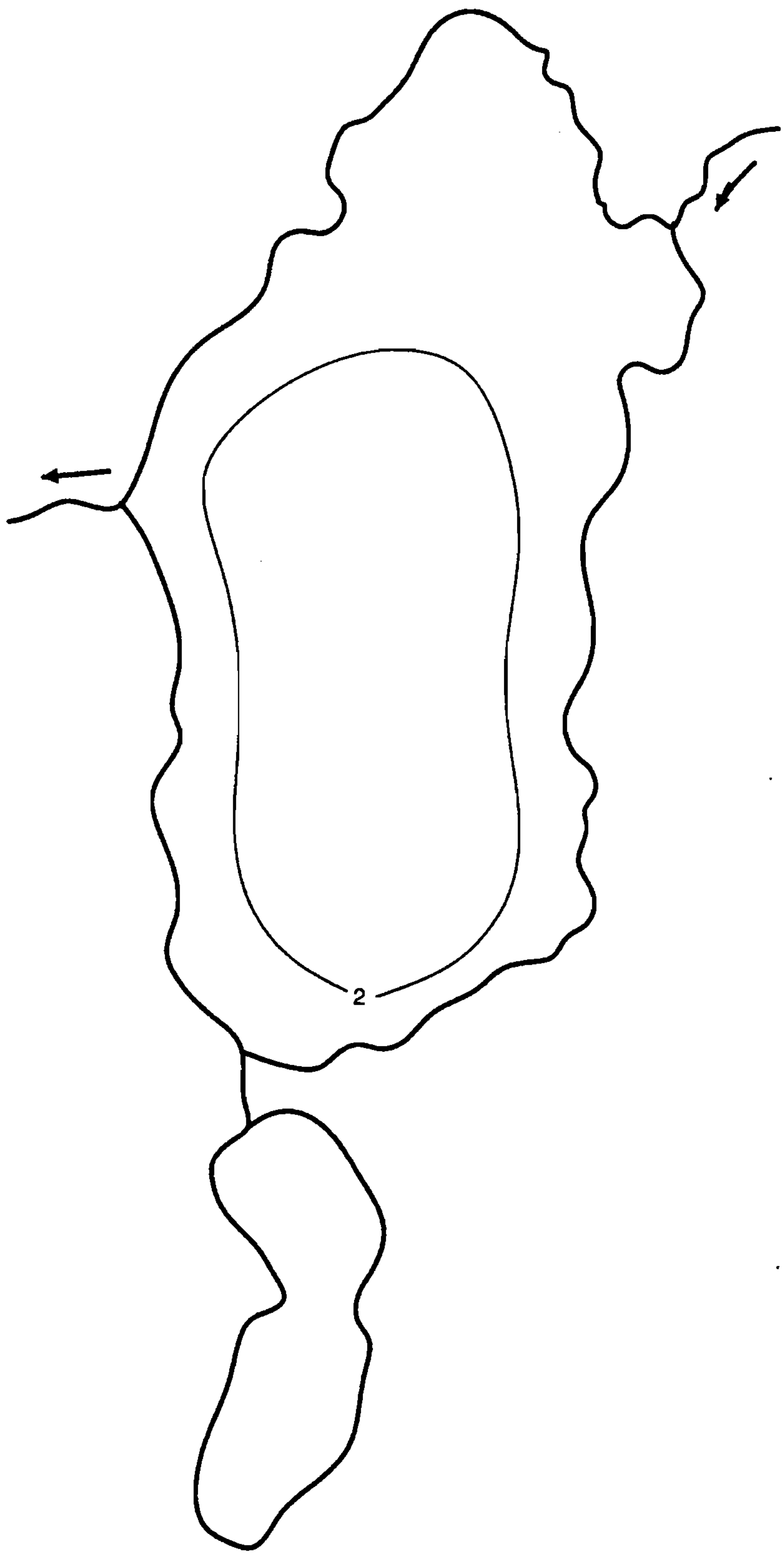


Area	= 9,550 ha
Volume	= 44,000x10^{4}m^{3}
Mean Depth	= 4.6 m

Fish Species

Lake Trout
Arctic Grayling
Round Whitefish
Cisco
Sustainable Yield = 9,600 kg/yr

Fox Lake



0 200 400 m

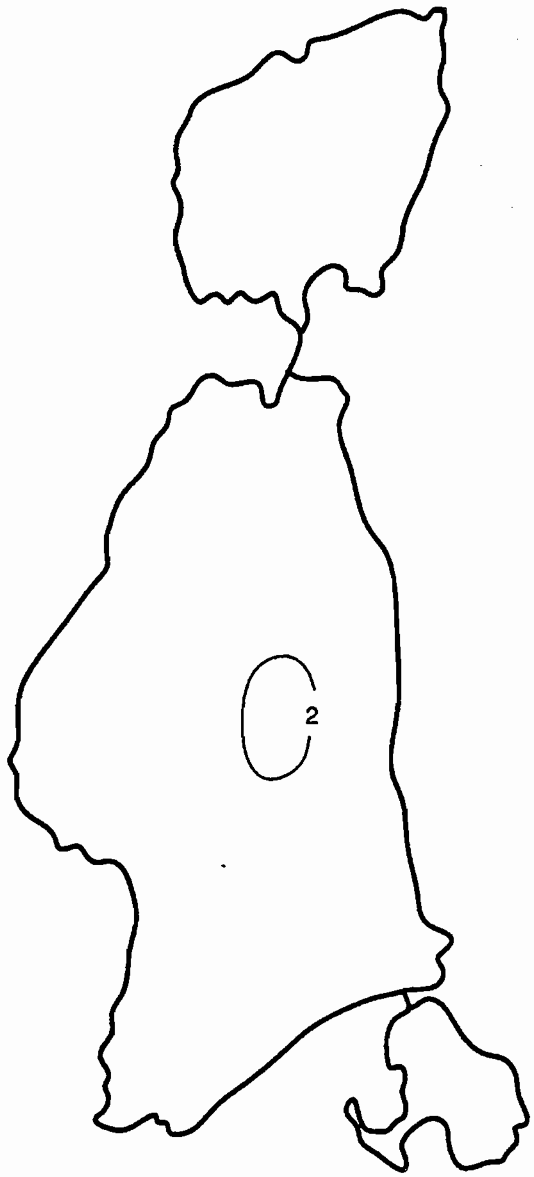
Depth Contours in Metres

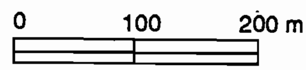
Area = 128 ha
Volume = 217×10^4 m^3
Mean Depth = 1.7 m

Fish Species

Lake Trout
Arctic Grayling
Sustainable Yield= 130 kg/yr

Meadow Lake



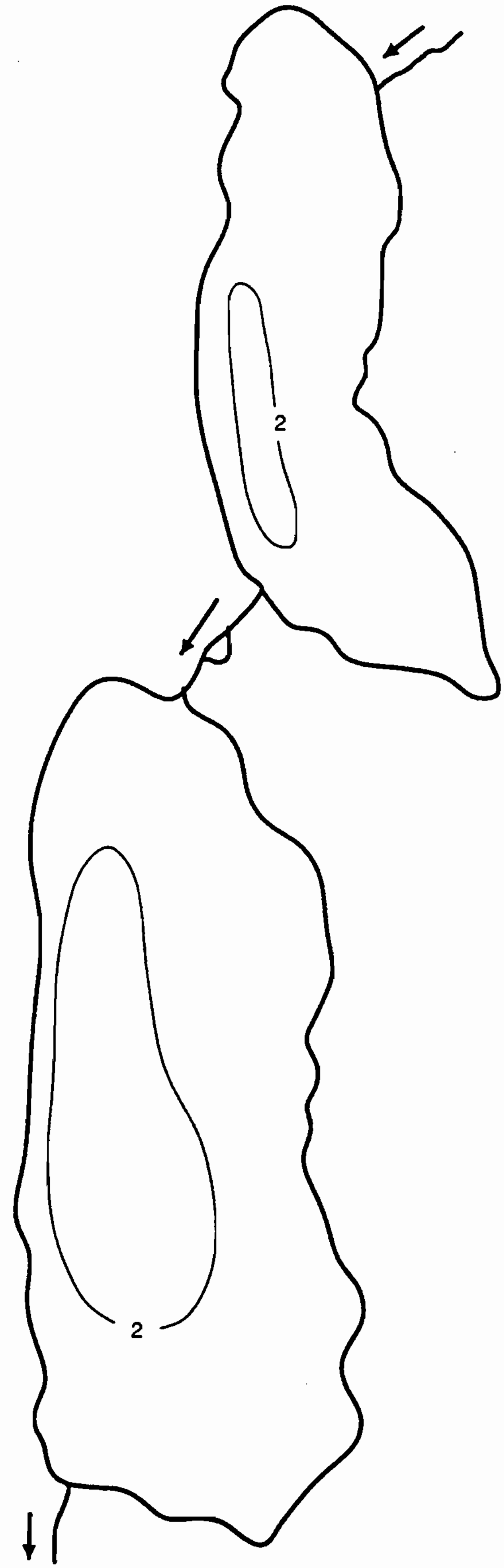


Depth Contours in Metres

Area =	14 ha
Volume =	$11.7 \times 10^4\ m^3$
Mean Depth =	0.8 m

Fish Species

None



Drum Lake

0 200 400 m

Depth Contours in Metres

N

Area = 25 ha
Volume = 32.5×10^4 m^3
Mean Depth = 1.3 m

Lin Lake

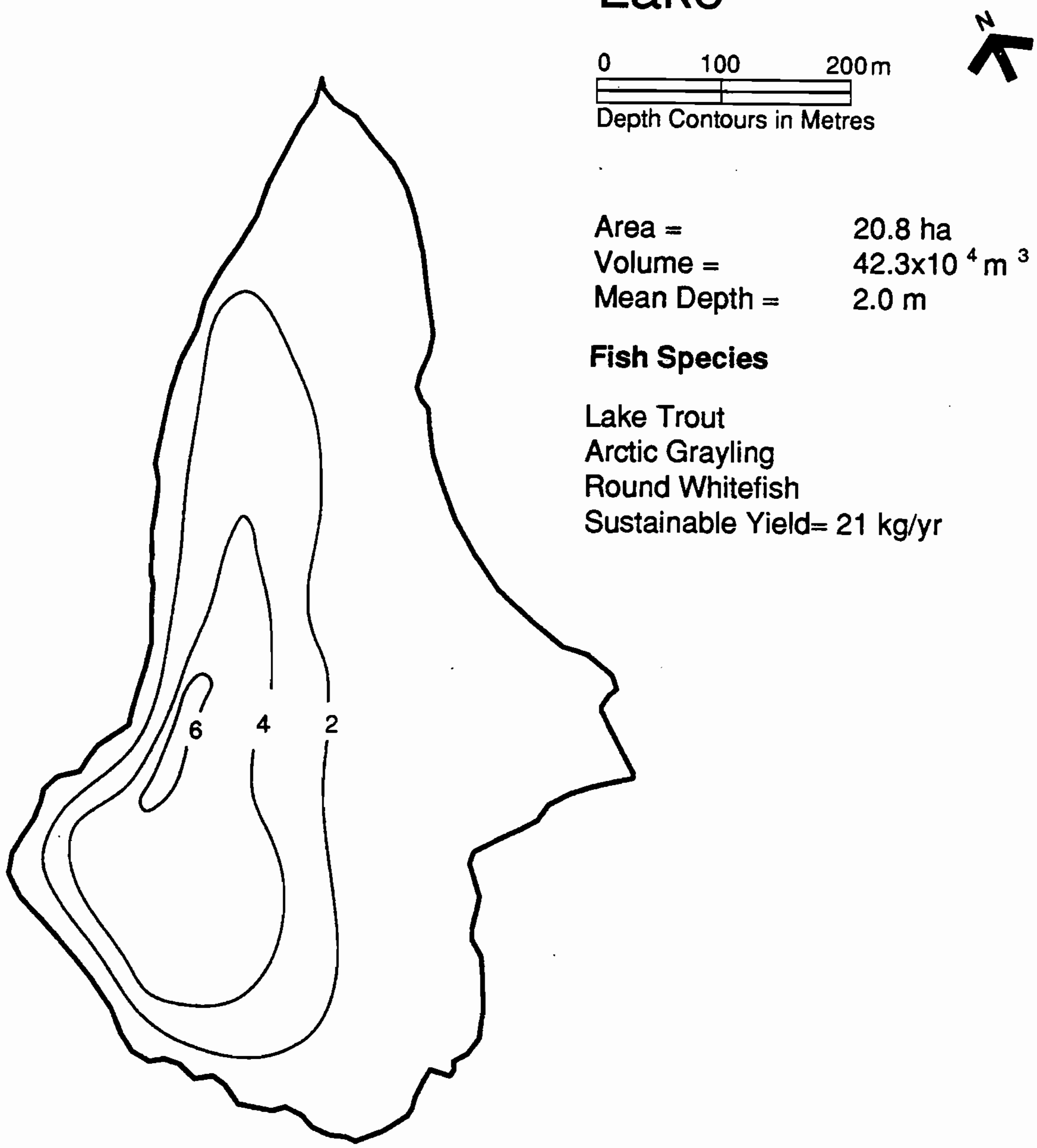
Depth Contours in Metres

Area = 48 ha
Volume = 63.2×10^4 m^3
Mean Depth = 1.3 m

Fish Species

Arctic Grayling
Sustainable Yield= 73 kg/yr
(Both Lakes)

Felsenmeer Lake



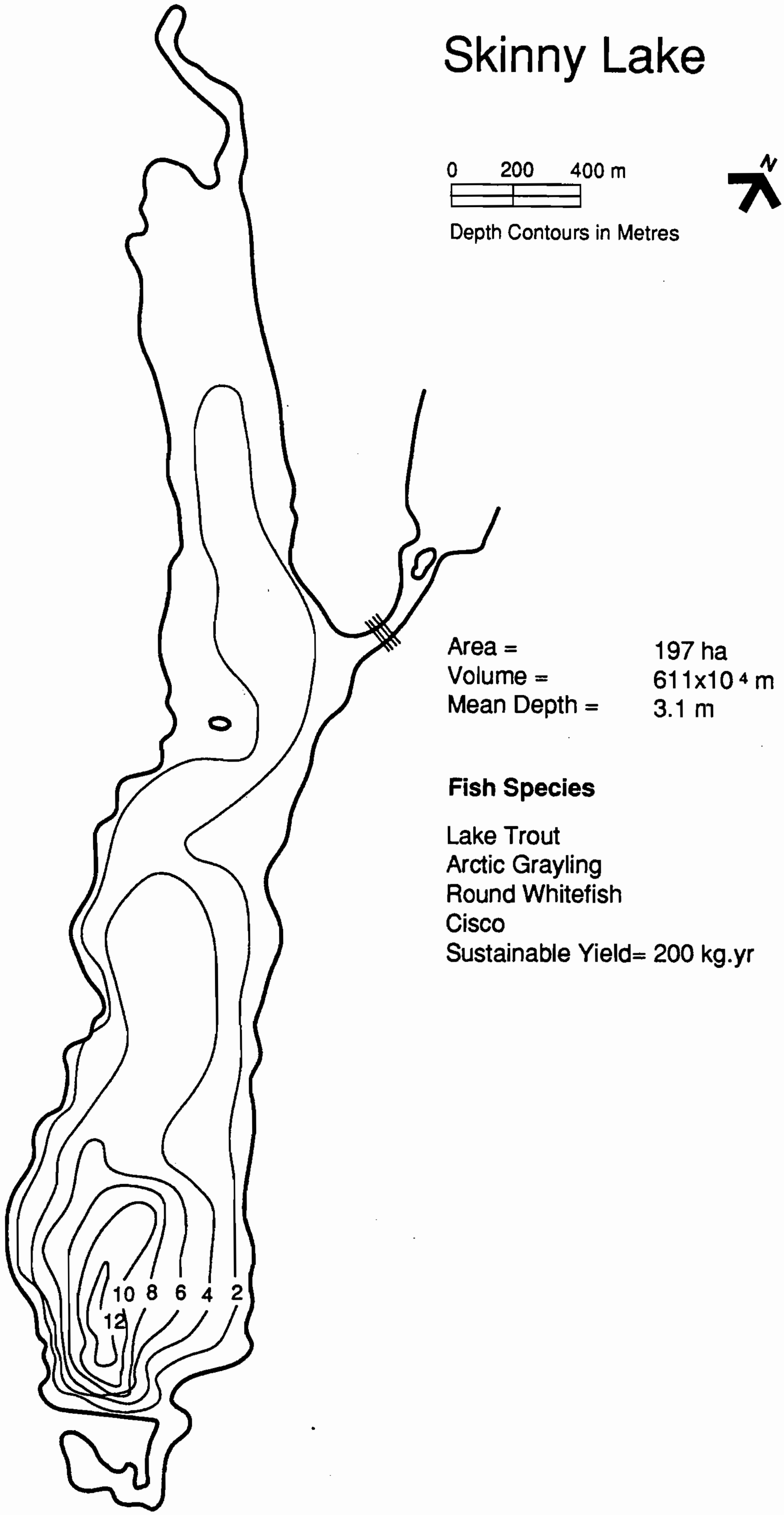
Depth Contours in Metres

Area =	20.8 ha
Volume =	$42.3x10^4 m^3$
Mean Depth =	2.0 m

Fish Species

Lake Trout
Arctic Grayling
Round Whitefish
Sustainable Yield= 21 kg/yr

Skinny Lake

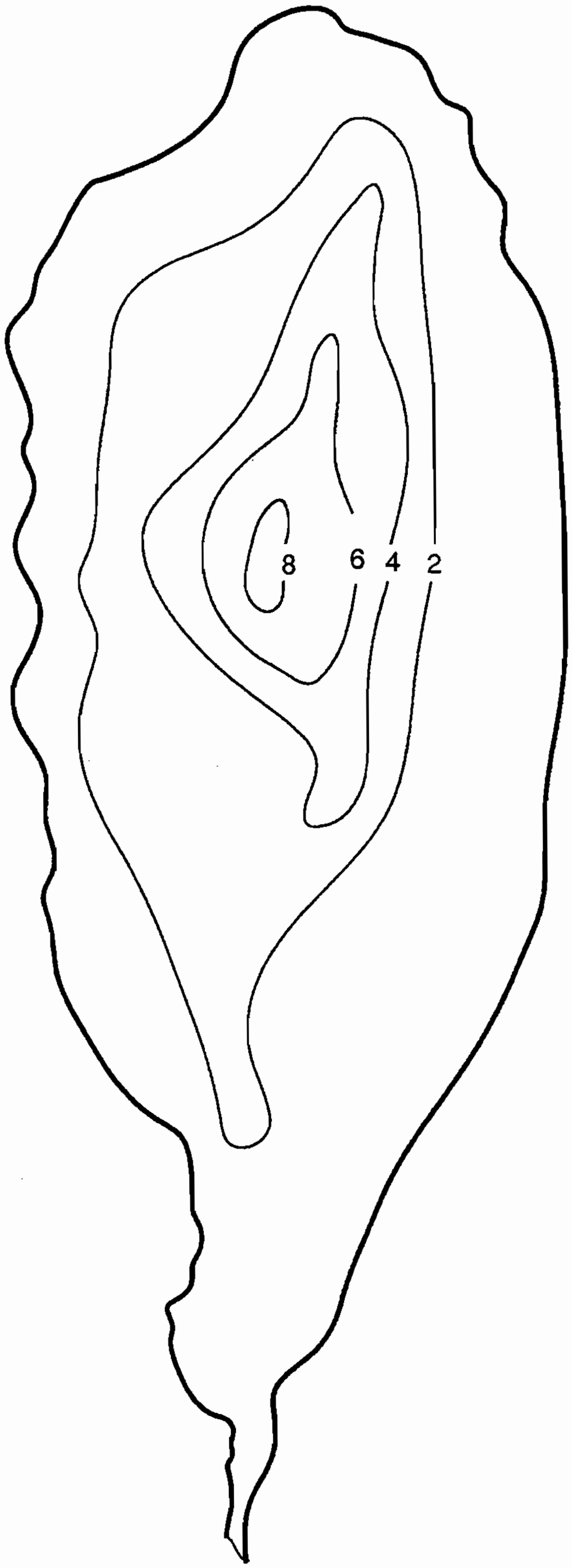


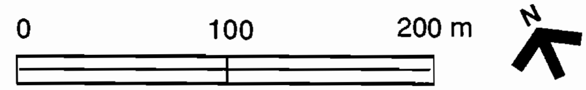
Area = 197 ha
Volume = 611x10^{4} m^{3}
Mean Depth = 3.1 m

Fish Species

Lake Trout
Arctic Grayling
Round Whitefish
Cisco
Sustainable Yield= 200 kg.yr

Escarpment Lake



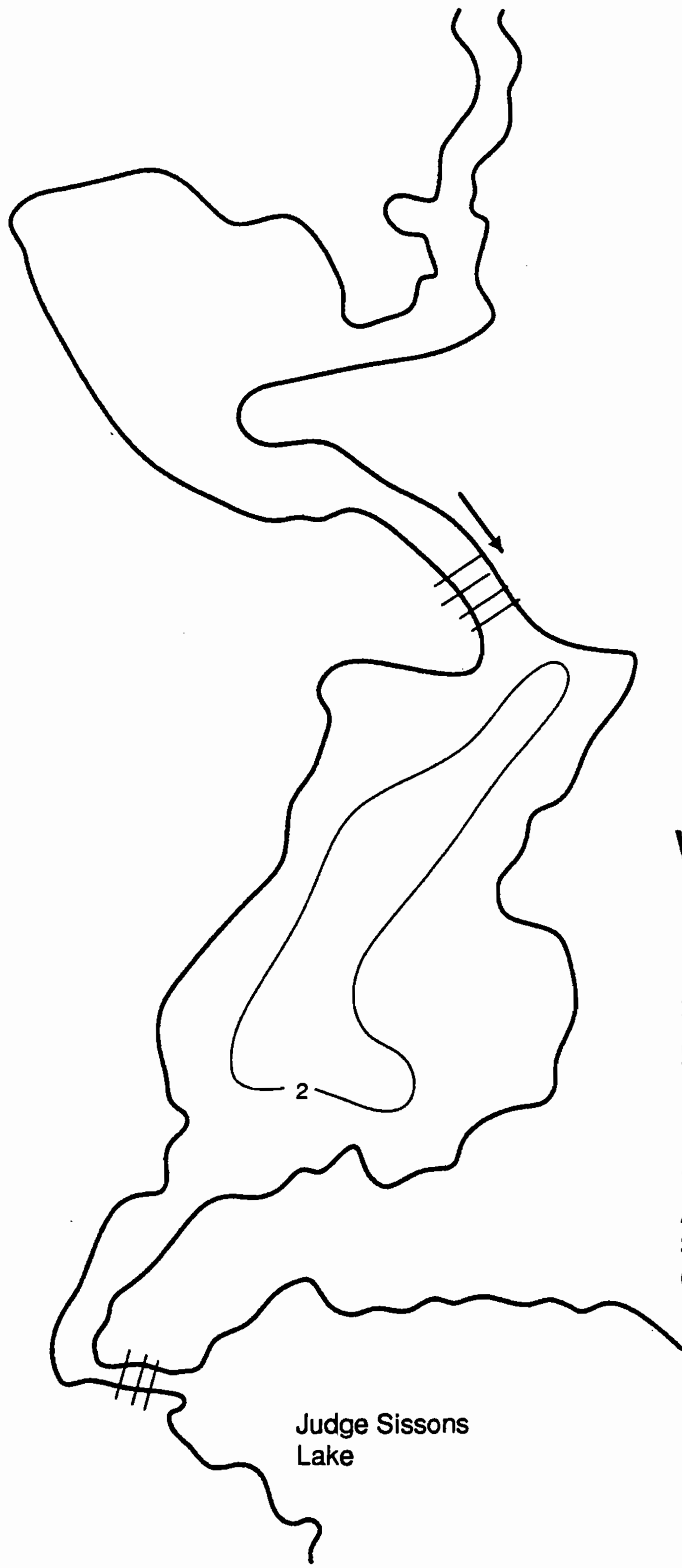


Depth Contours in Metres

Area =	12.7 ha
Volume =	28×10^4 m^3
Mean Depth =	2.2 m

Fish Species

Lake Trout
Arctic Grayling
Round Whitefish
Sustainable Yield = 13 kg/yr



Rock Lake

0 200 400 m

N

Depth Contours in Metres

Area = 26.9 ha
Volume = 37.7×10^4 m ^{3}
Mean Depth = 1.4 m

Willow Lake

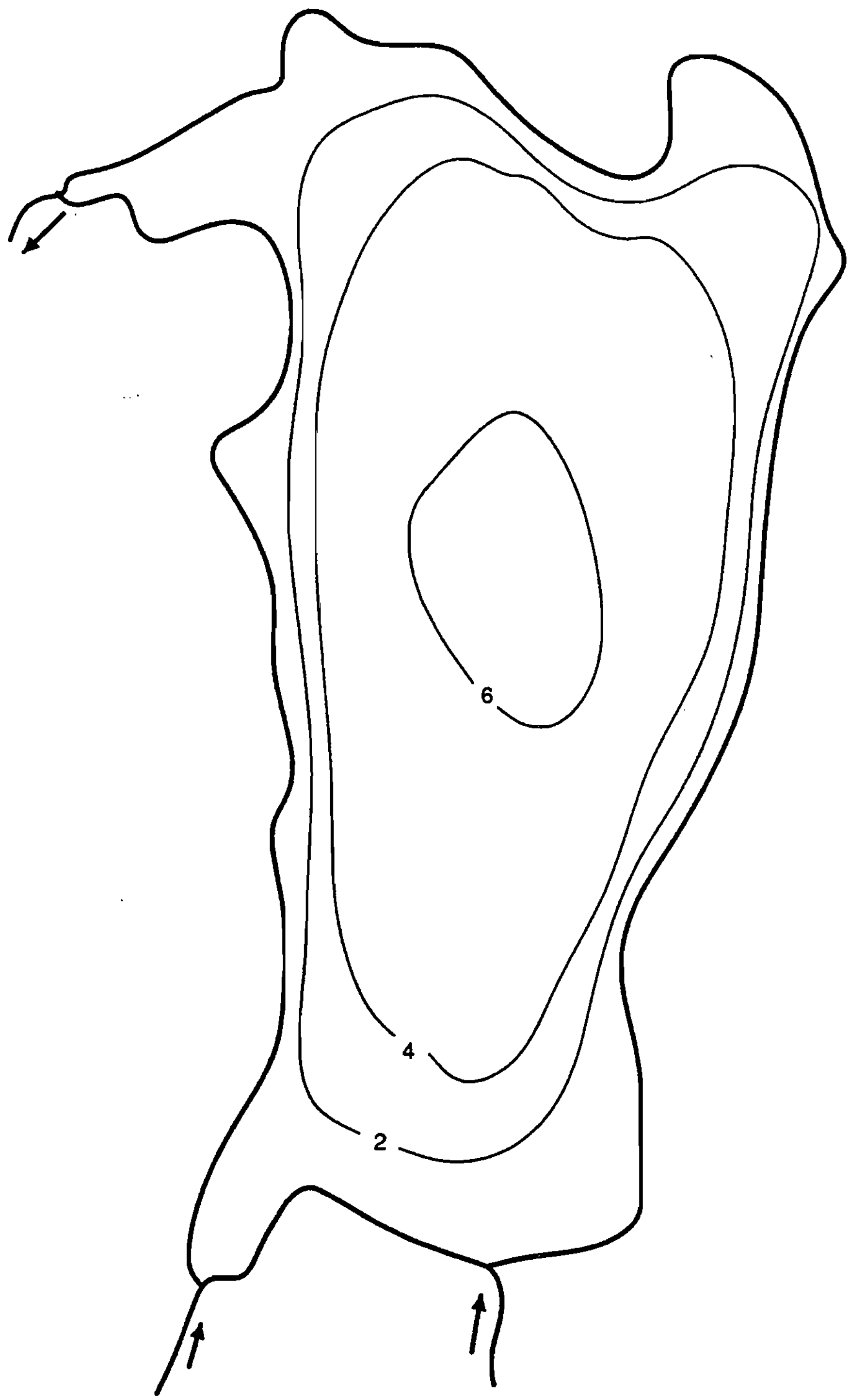
Depth Contours in Metres

Area = 54.9 ha
Volume = 76.6×10^4 m ^{3}
Mean Depth = 1.4 m

Fish Species

Lake Trout
Arctic Grayling
Sustainable Yield= 82 kg/yr
(Both Lakes)

Scotch Lake



0 250 500 m

N

Depth Contours in Metres

Area = 195 ha
Volume = $710x10^4$ m^3
Mean Depth = 3.6 m

Fish Species

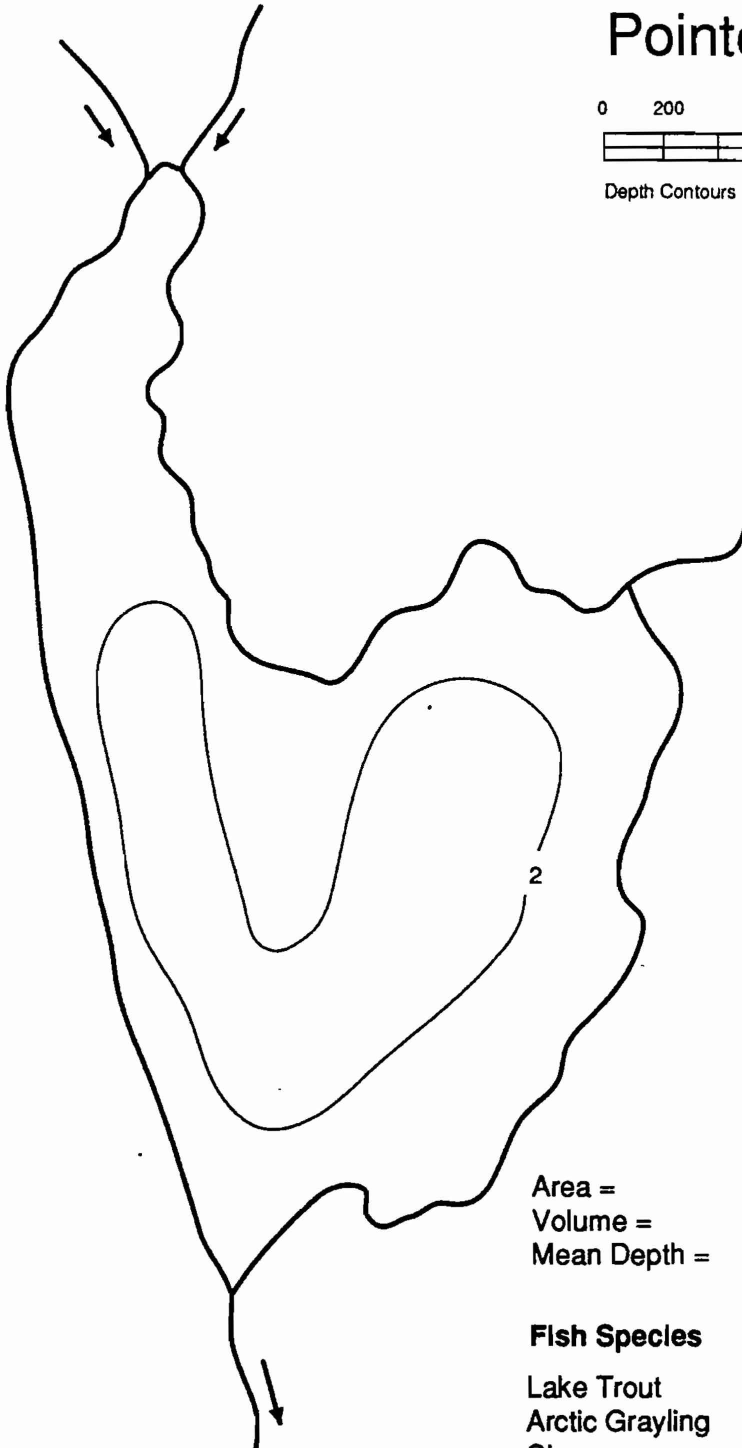
Lake Trout
Round Whitefish
Sustainable Yield = 200 kg/yr

Pointer Lake

0 200 600 m

Depth Contours in Metres

N

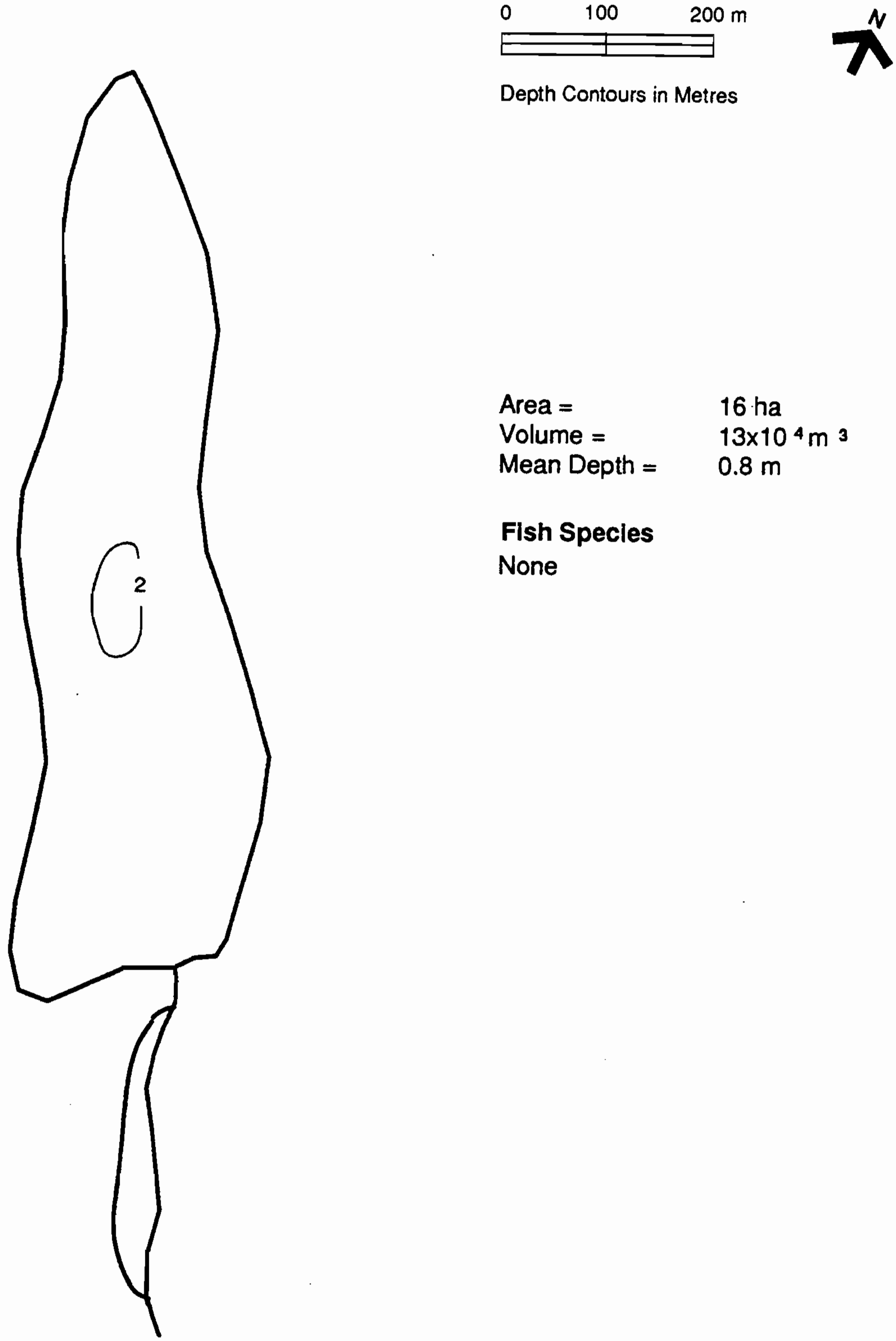


Area = 374 ha
Volume = 559×10^4 m^3
Mean Depth = 1.5 m

Fish Species

Lake Trout
Arctic Grayling
Cisco
Sustainable Yield = 370 kg/yr

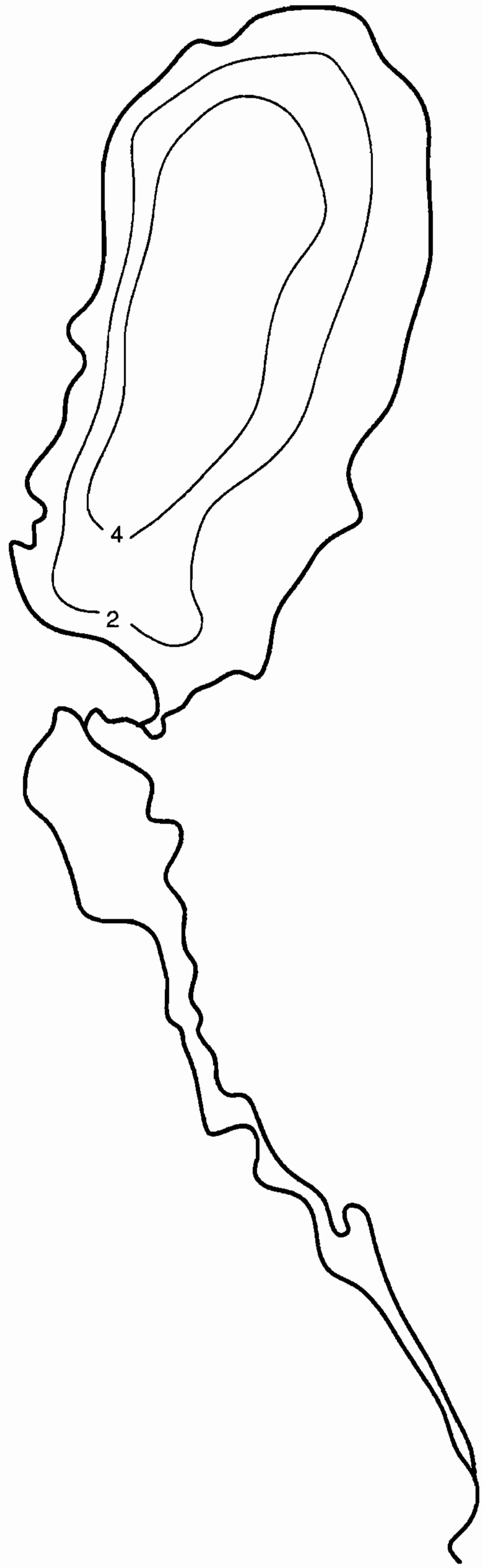
Sik Sik Lake



Depth Contours in Metres

Area = 16 ha
Volume = $13x10^4 m^3$
Mean Depth = 0.8 m

Fish Species
None



Cirque Lake

0 100 200 m

Depth Contours in Metres

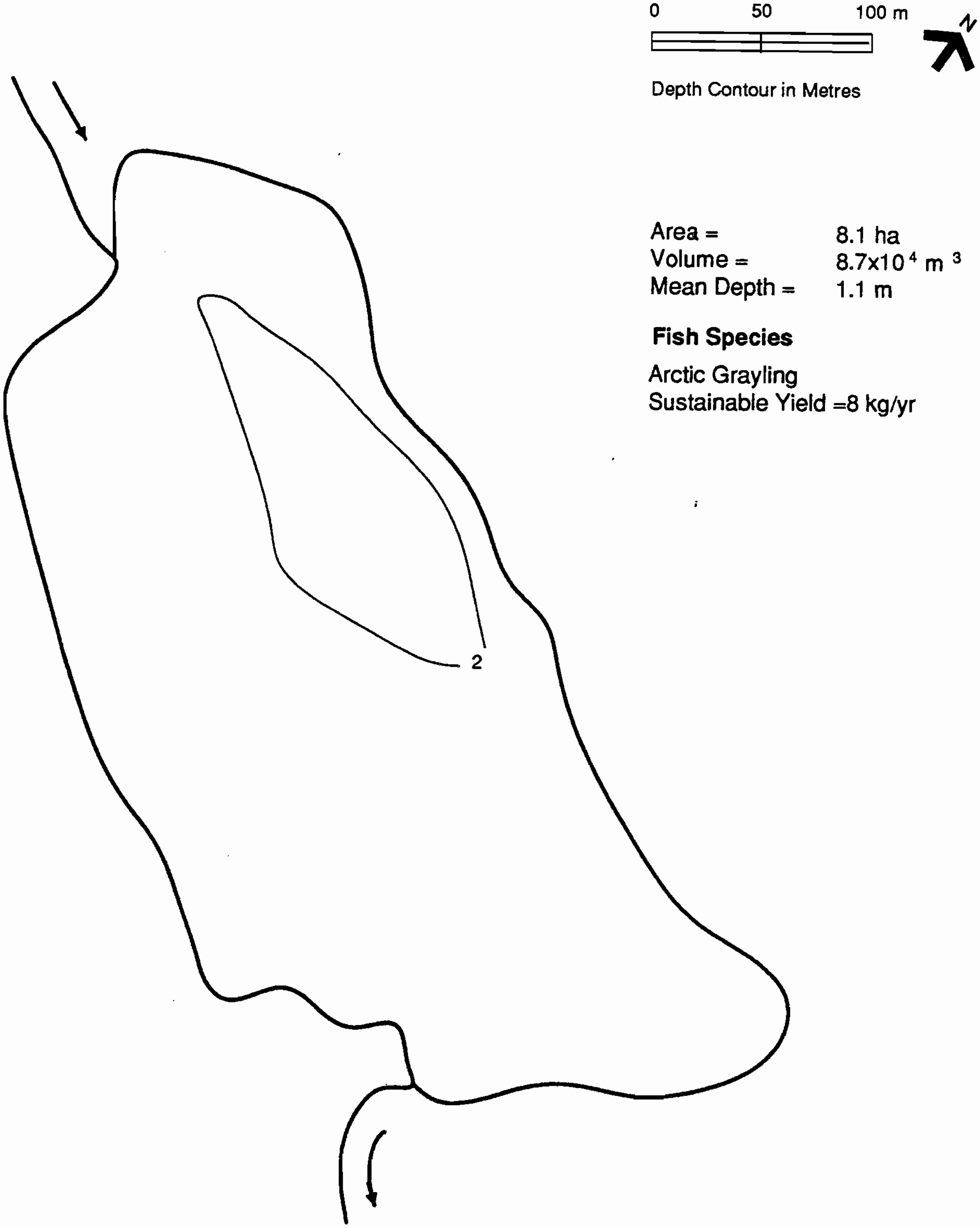
Area =	5.6 ha
Volume =	14.6×10^4 m^3
Mean Depth =	2.6 m

Fish Species

Arctic Grayling

Sustainable Yield =6 kg/yr

Crash Lake

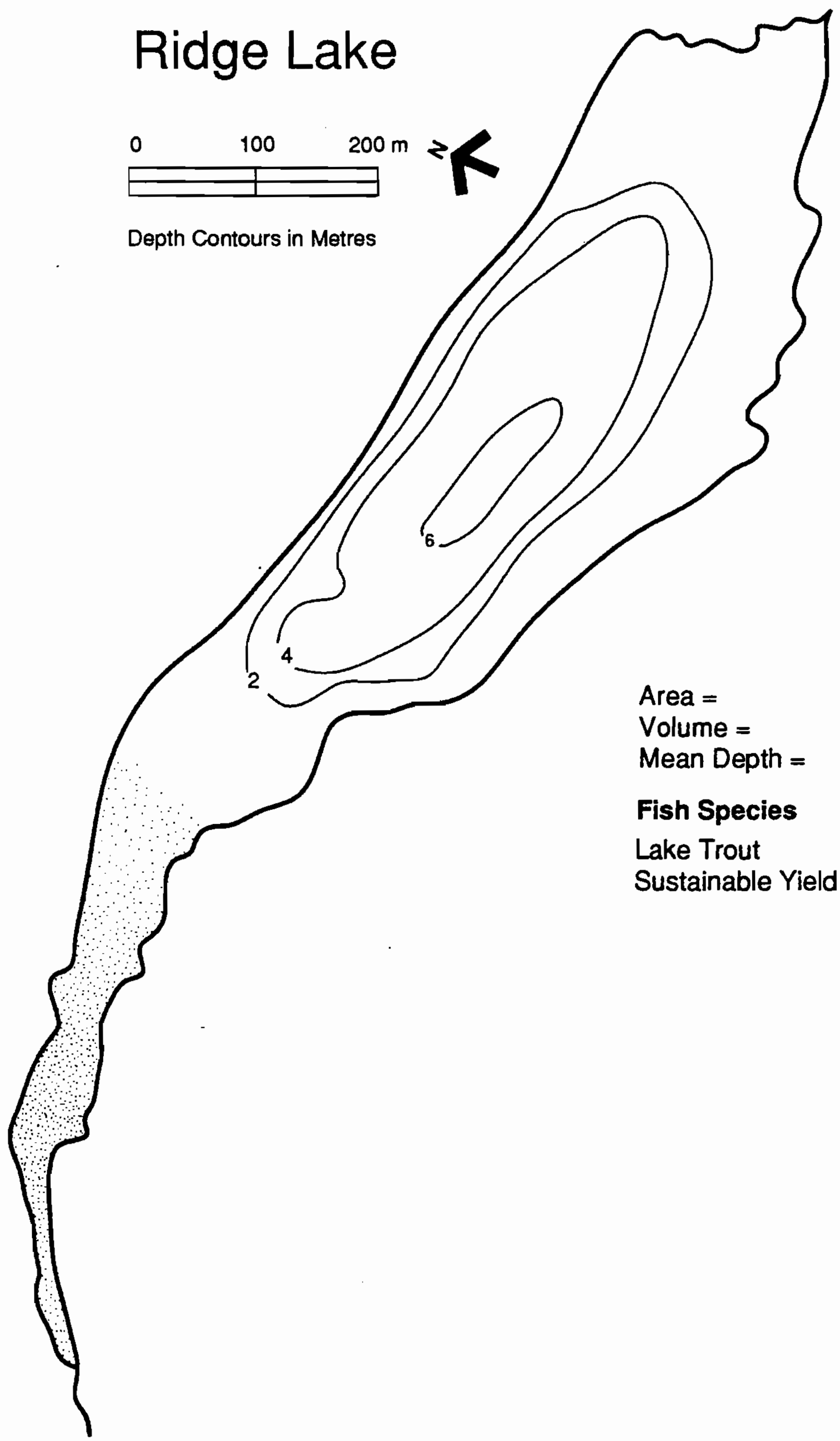


Area = 8.1 ha
Volume = $8.7 \times 10^4\ m^3$
Mean Depth = 1.1 m

Fish Species

Arctic Grayling
Sustainable Yield =8 kg/yr

Ridge Lake



Area =	16.7 ha
Volume =	$38.4x10^4 m^3$
Mean Depth =	2.3 m

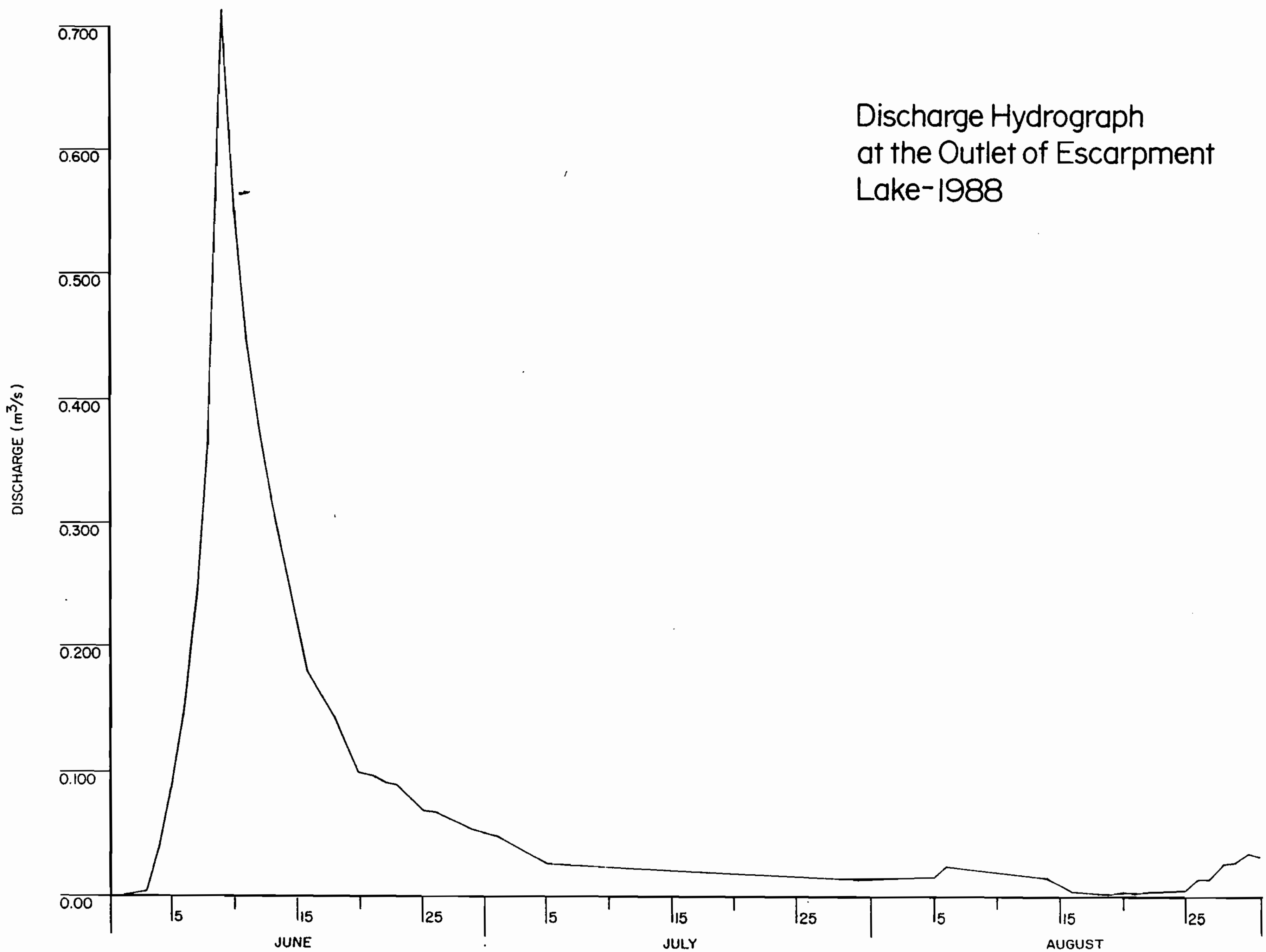
Fish Species

Lake Trout

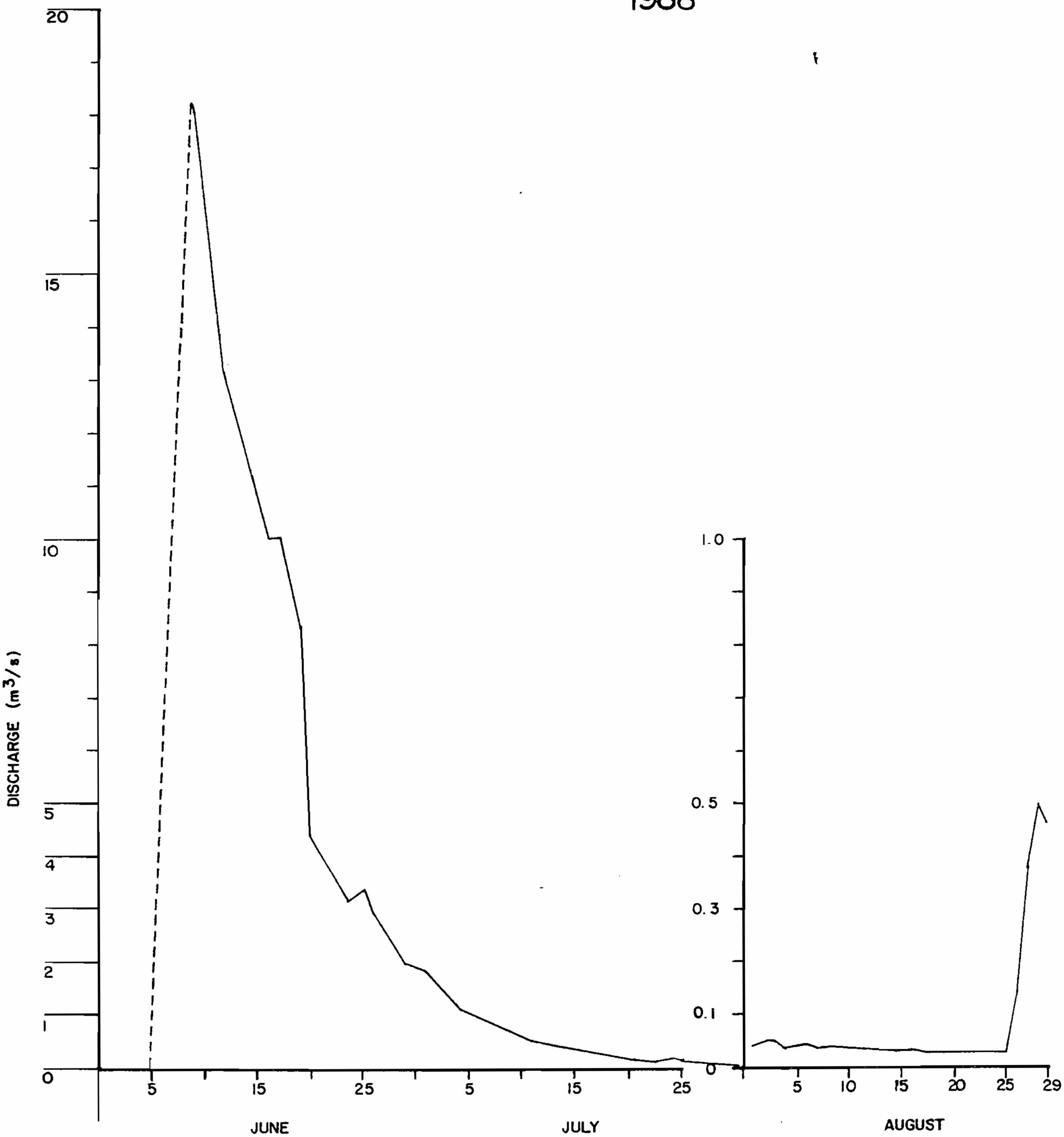
Sustainable Yield =17 kg/yr

APPENDIX 2

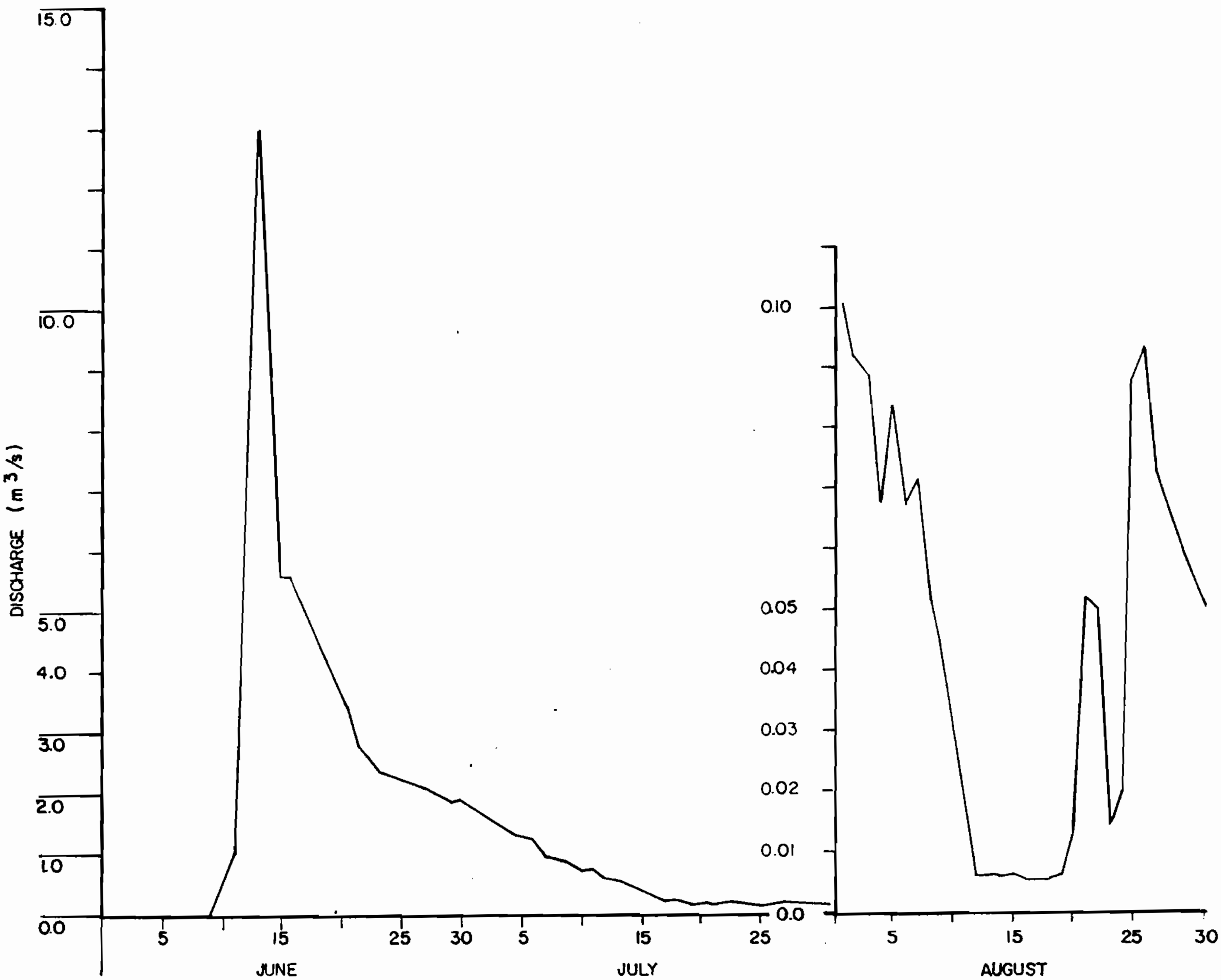
Outflow Hydrographs


Discharge Hydrograph
at the Outlet of Escarpment
Lake-1988
DISCHARGE (m3/s)
0.700
0.600
0.500
0.400
0.300
0.200
0.100
0.00
5
15
25
5
15
25
5
15
25
JUNE
JULY
AUGUST

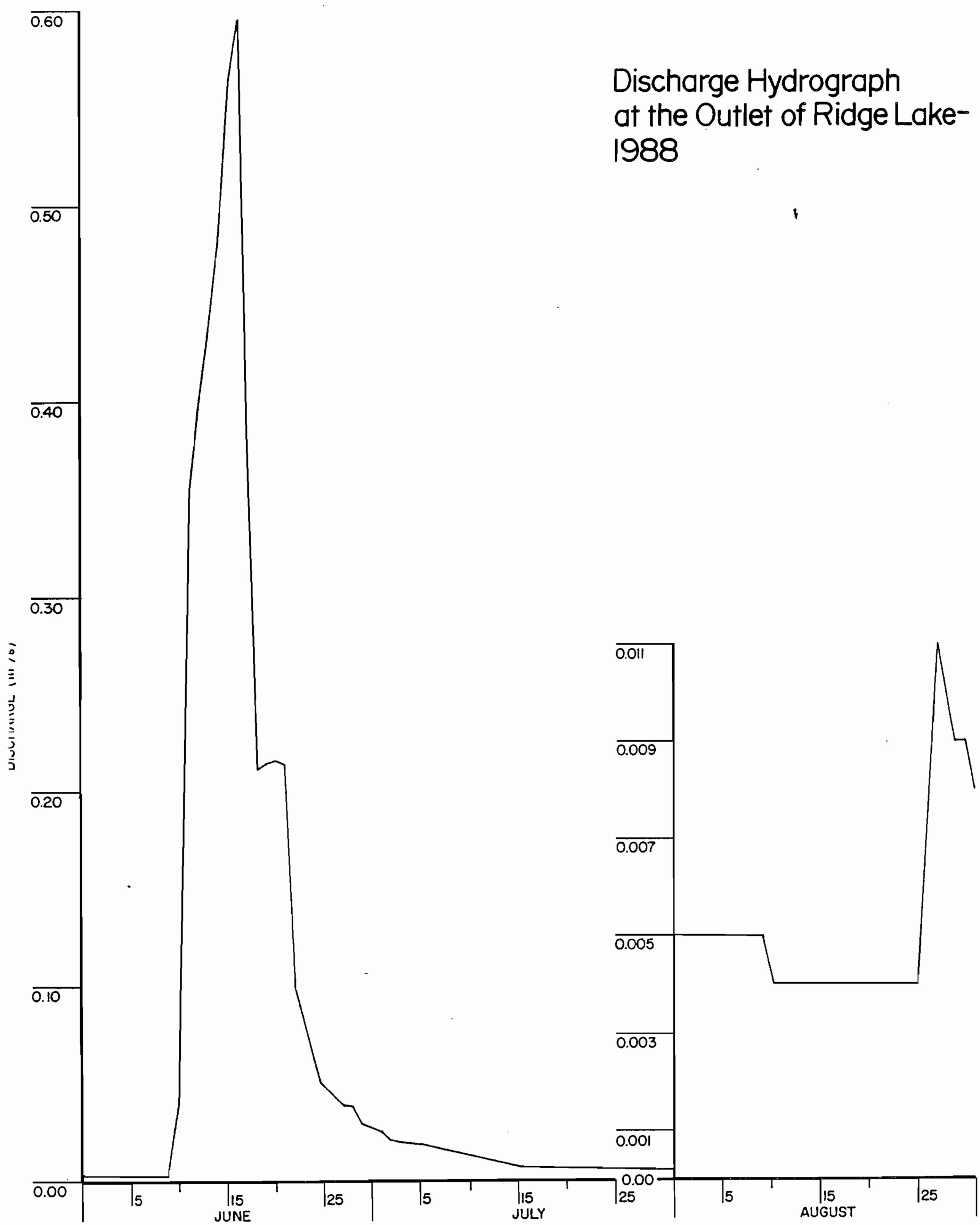
Discharge Hydrograph at the Outlet of Skinny Lake 1988

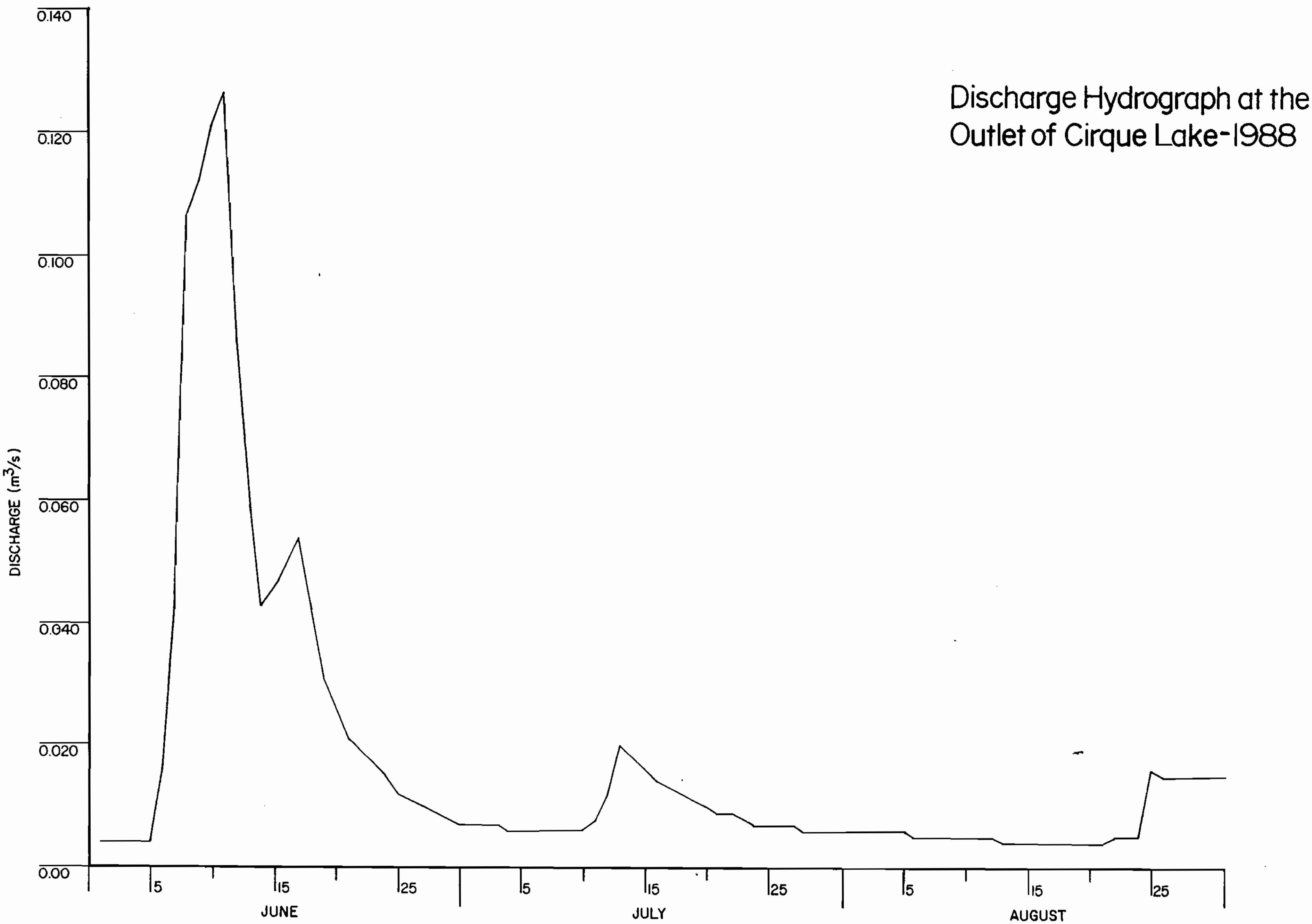


Discharge Hydrograph at the Outlet of Jaeger Lake 1988

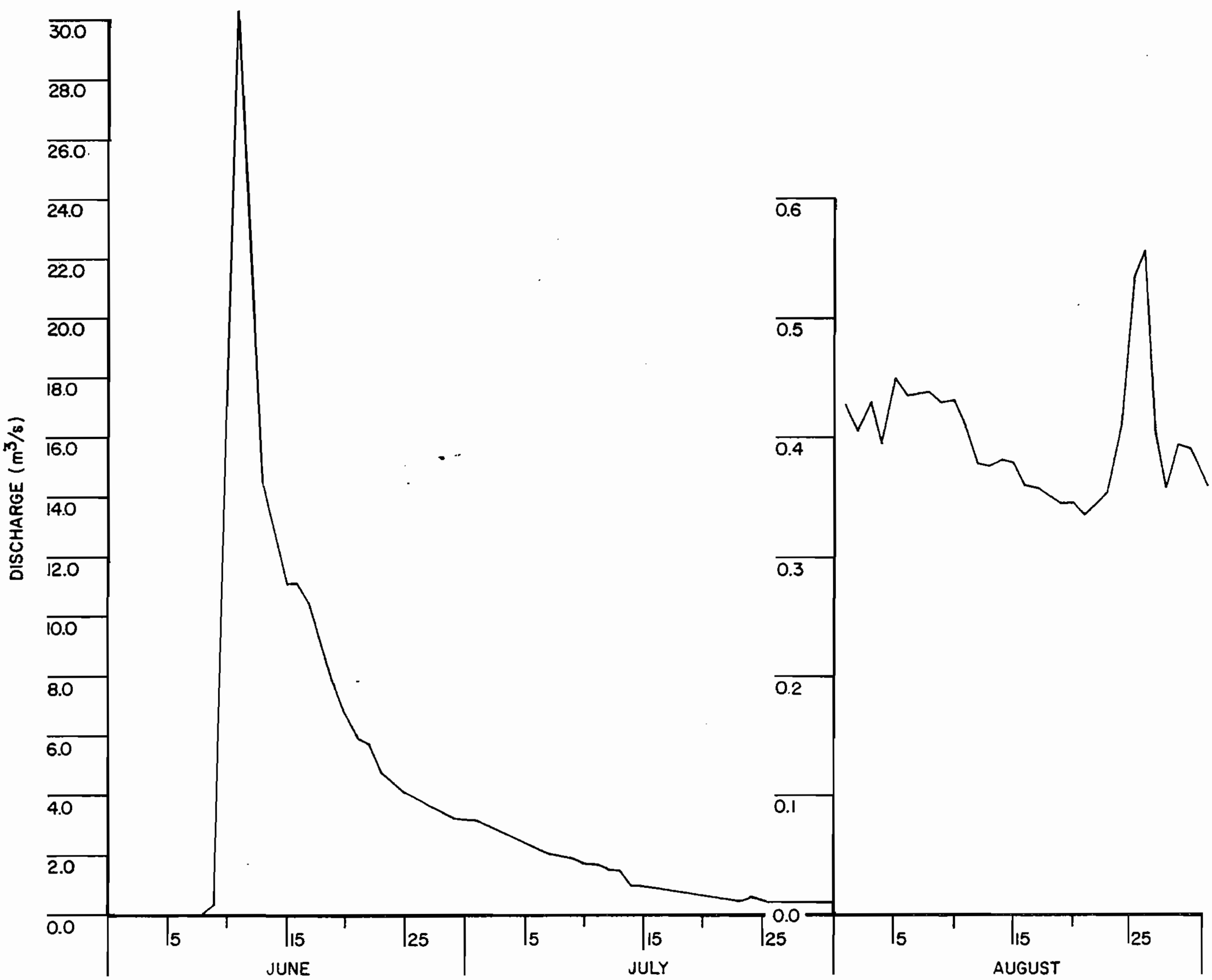


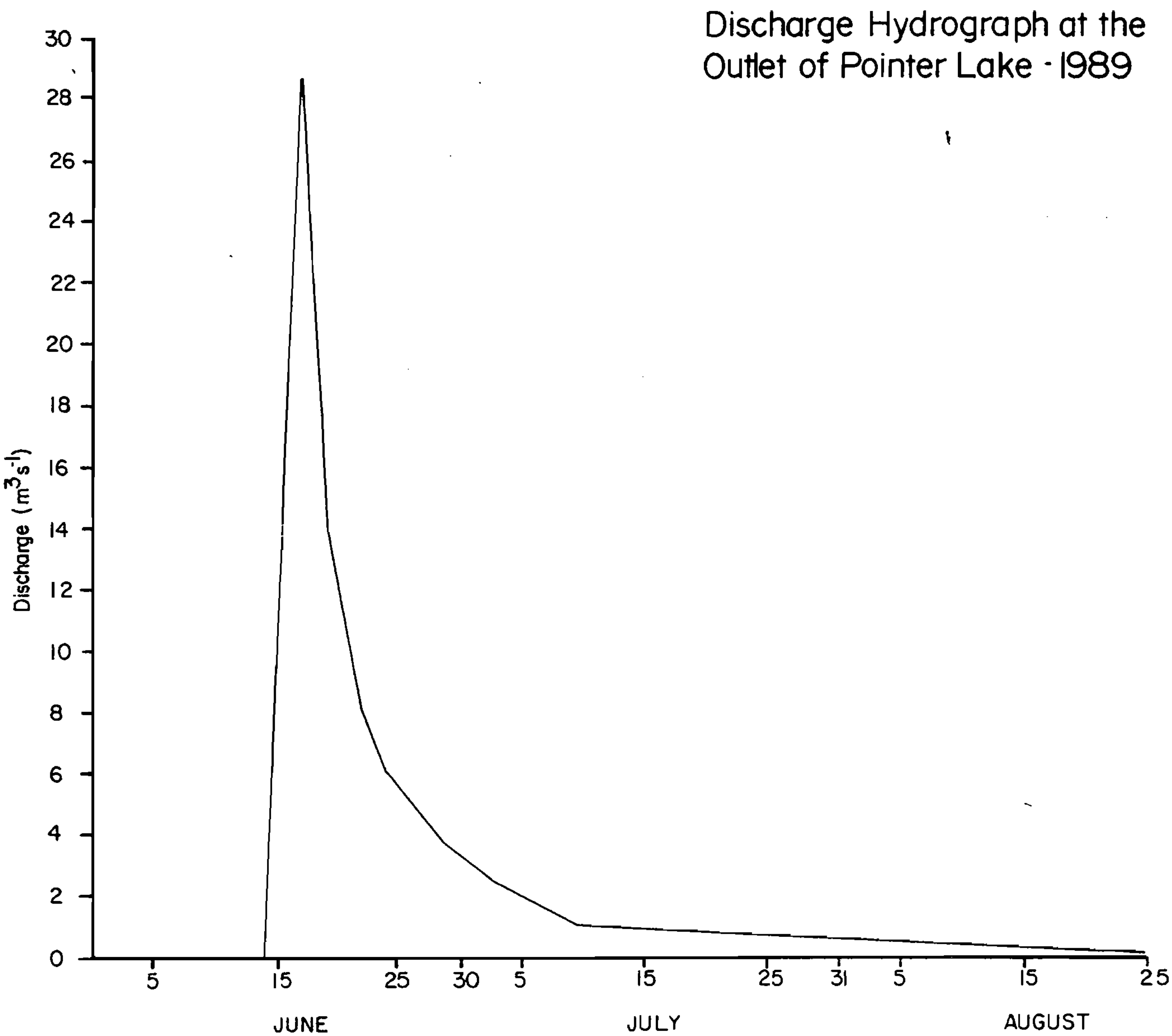
Discharge Hydrograph at the Outlet of Ridge Lake-1988




Discharge Hydrograph at the Outlet of Cirque Lake-1988
DISCHARGE (m3/s)
0.140
0.120
0.100
0.080
0.060
0.040
0.020
0.00
5
15
25
JUNE
5
15
25
JULY
5
15
25
AUGUST

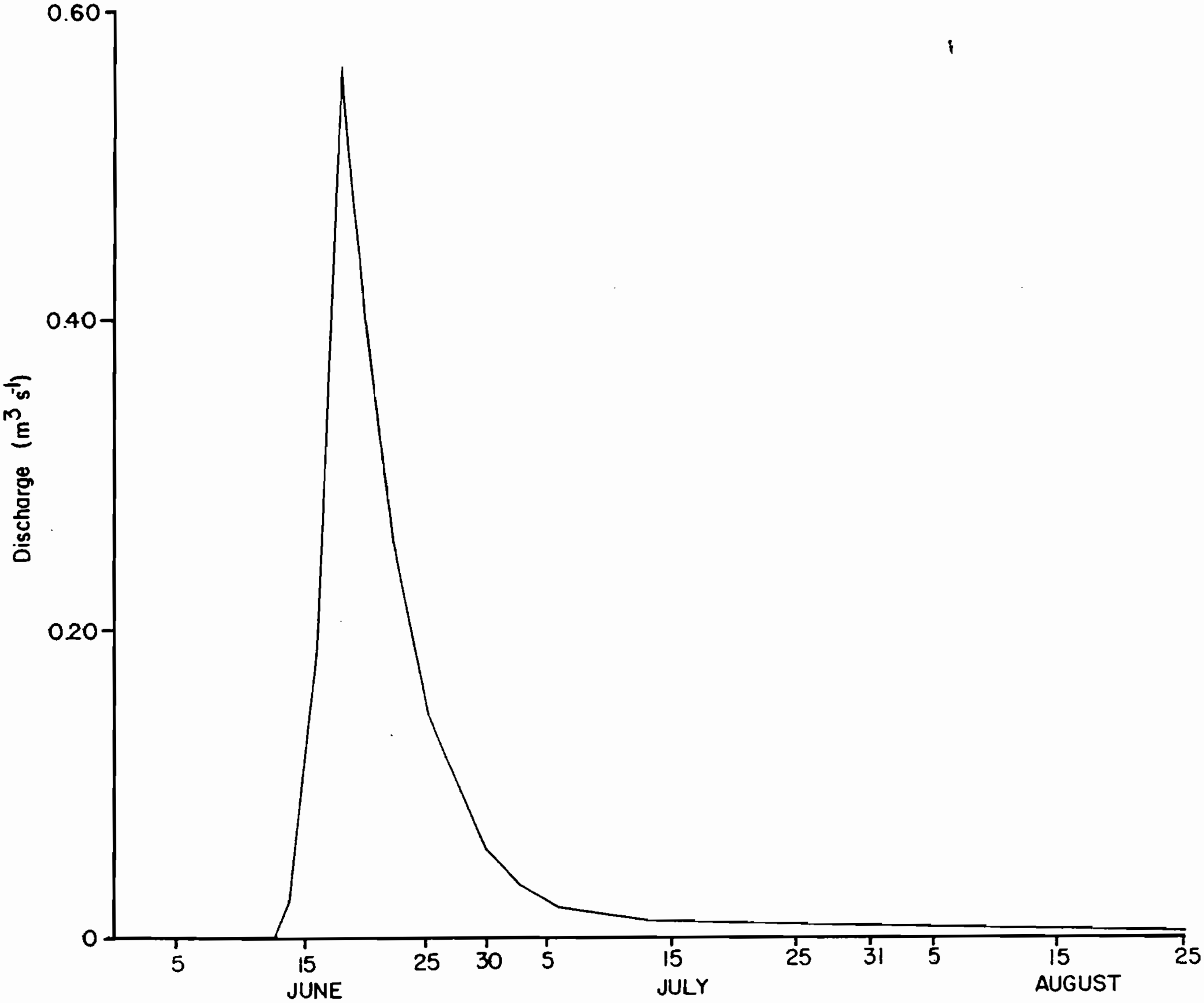
Discharge Hydrograph at the Outlet of Pointer Lake 1988

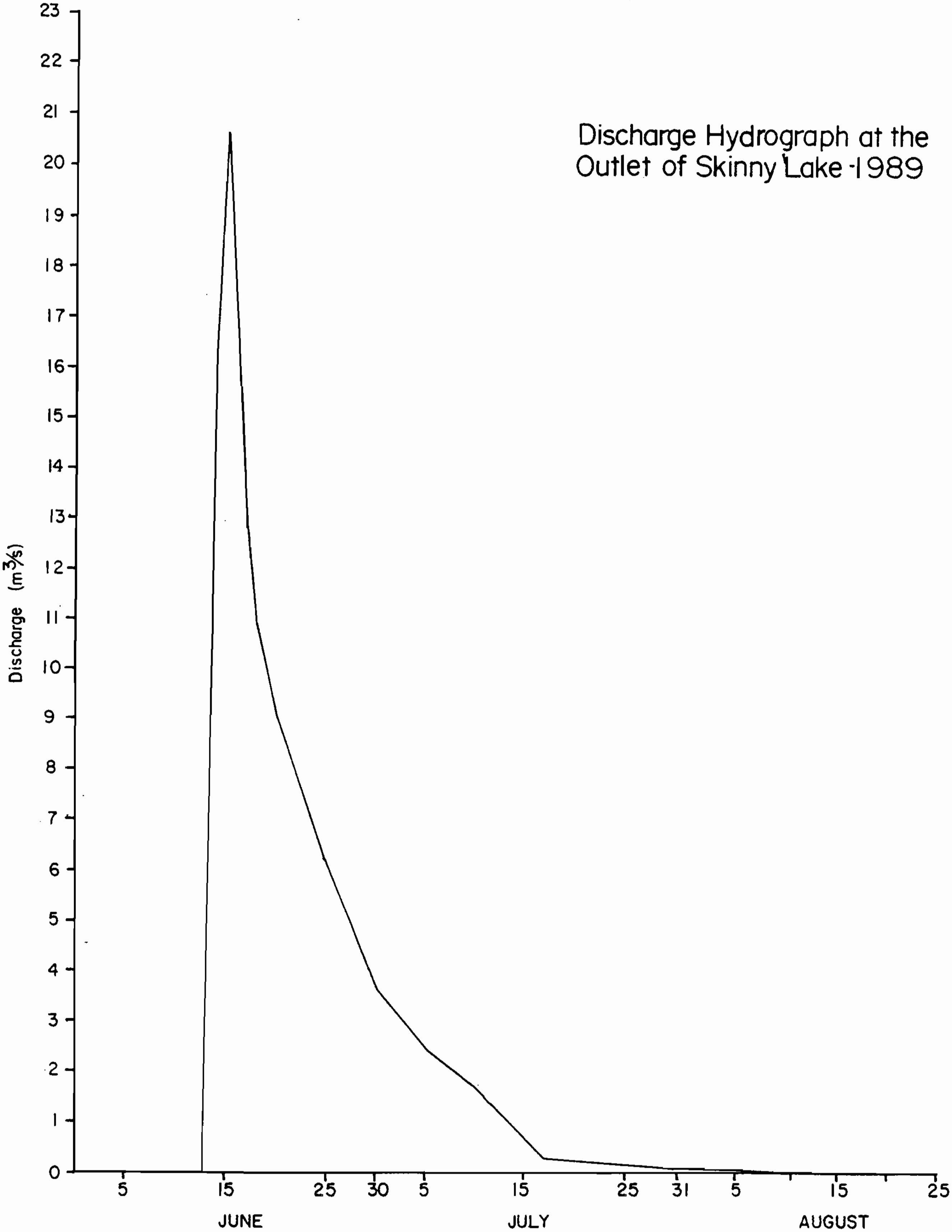




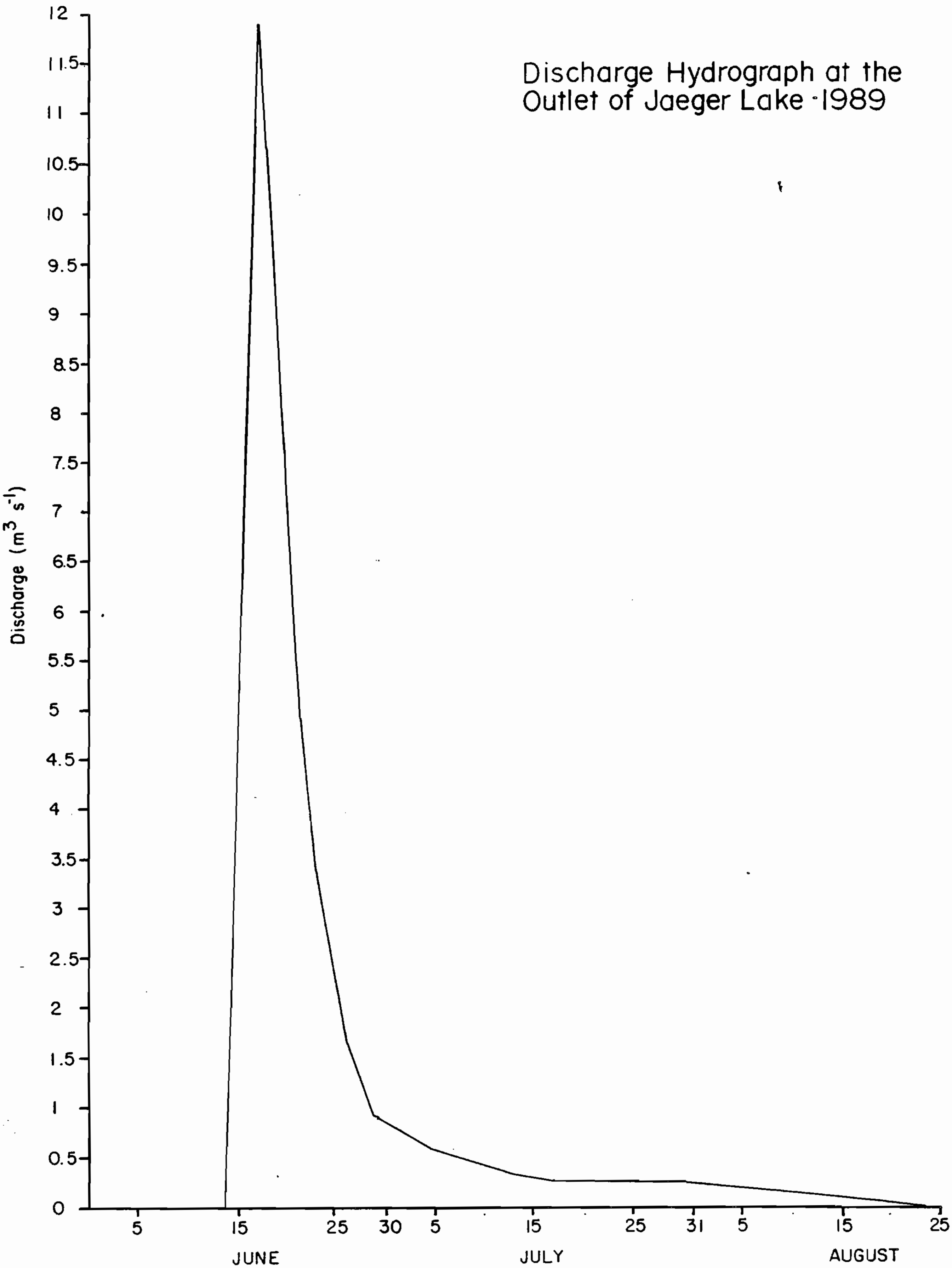
Discharge Hydrograph at the Outlet of Pointer Lake - 1989
Discharge ($m^3 s^{-1}$)
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
5
15
25
30
5
15
25
31
5
15
25
JUNE
JULY
AUGUST

Discharge Hydrograph at the Outlet of Ridge Lake - 1989



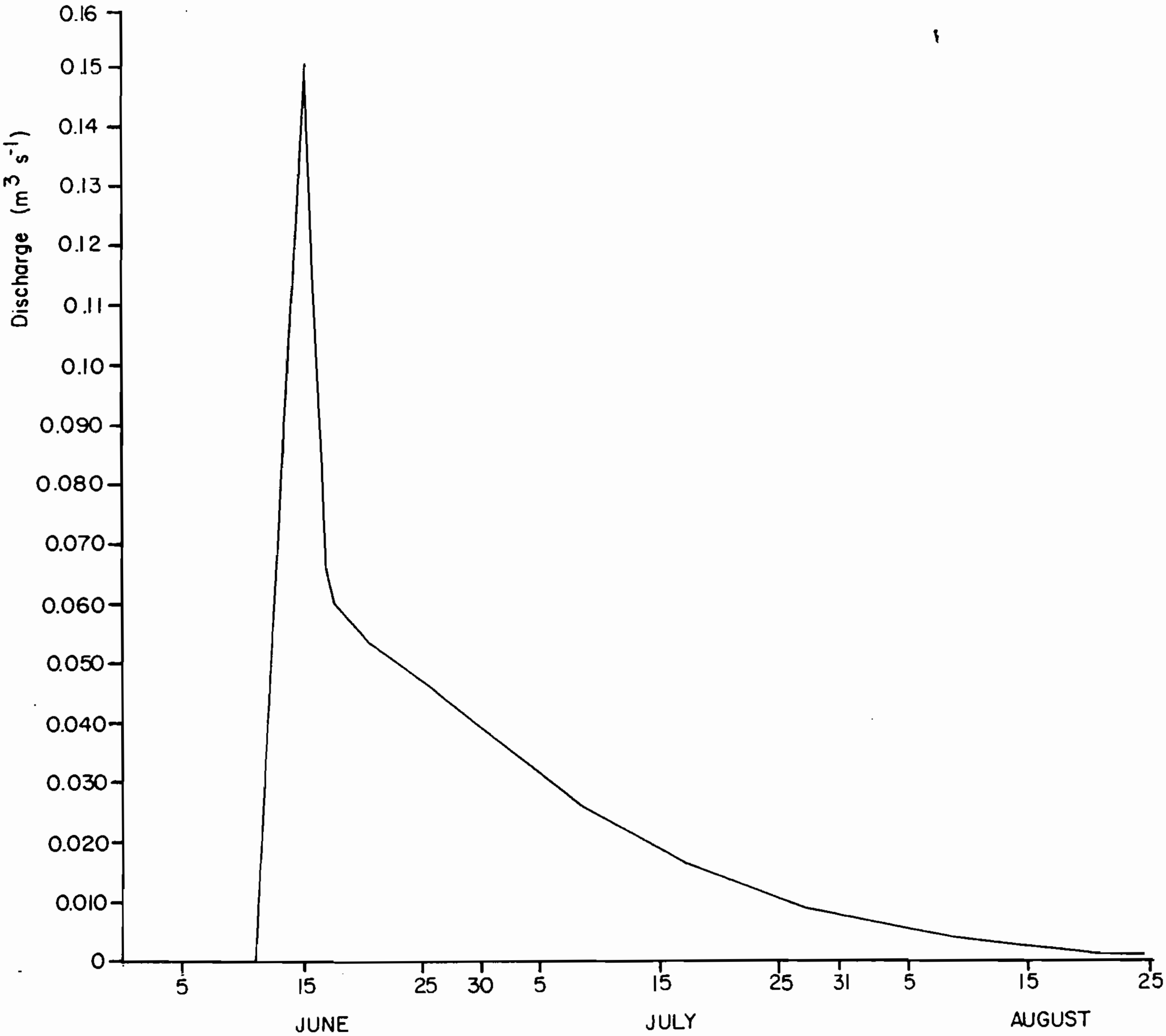


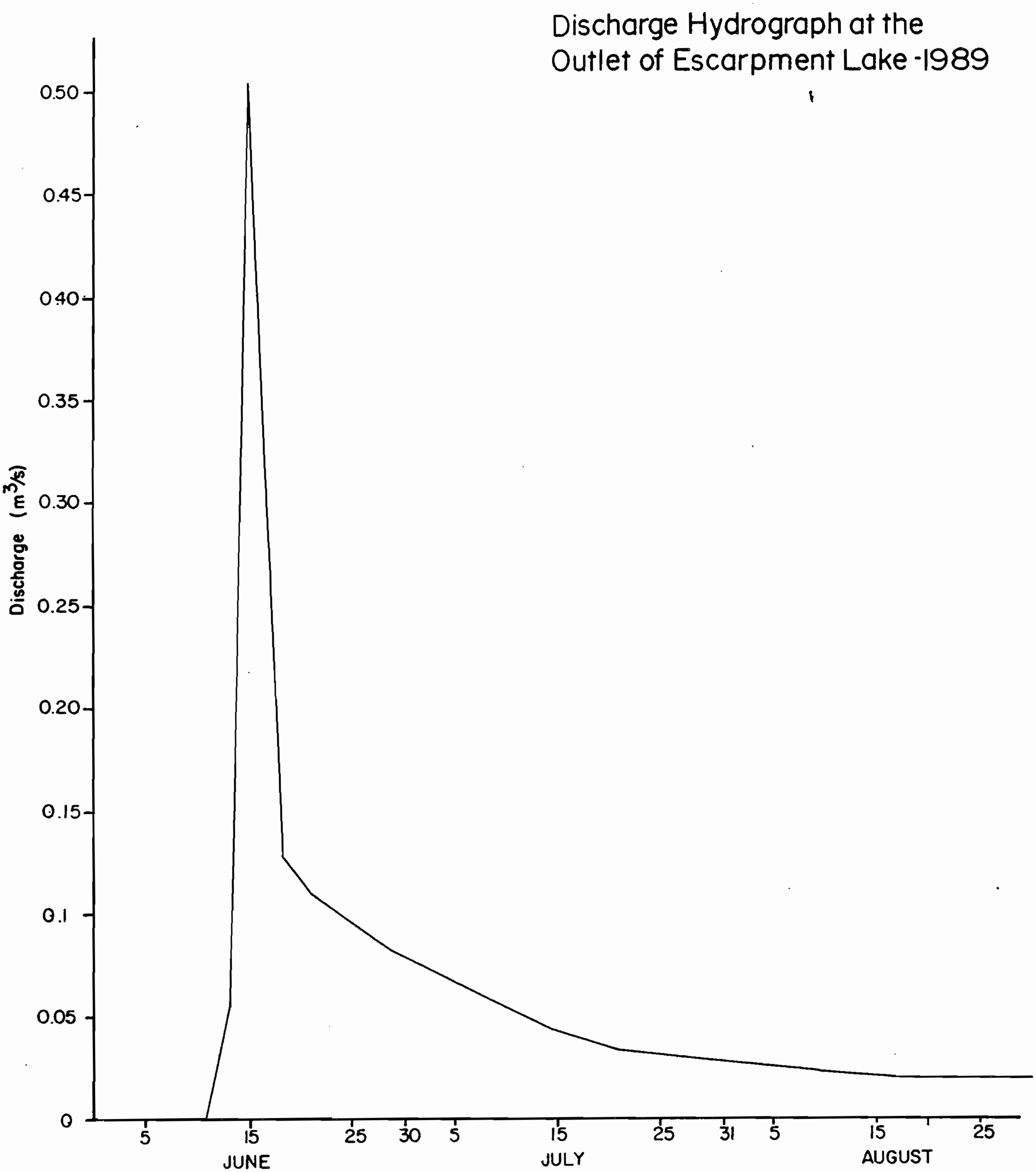
Discharge Hydrograph at the
Outlet of Skinny Lake -1989
Discharge (m3/s)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
5
15
25
30
5
15
25
31
5
15
25
JUNE
JULY
AUGUST



Discharge Hydrograph at the
Outlet of Jaeger Lake -1989
Discharge (m3 s-1)
12
11.5
11
10.5
10
9.5
9
8.5
8
7.5
7
6.5
6
5.5
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
5
15
25
30
5
15
25
31
5
15
25
JUNE
JULY
AUGUST

Discharge Hydrograph at the Outlet of Cirque Lake-1989




Discharge Hydrograph at the
Outlet of Escarpment Lake -1989
Discharge (m³/s)
0.50
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.1
0.05
0
5
15
25
30
5
15
25
31
5
15
25
JUNE
JULY
AUGUST

APPENDIX 3

Analytical Quality Assurance/Quality Control

APPENDIX 3: ANALYTICAL QUALITY ASSURANCE/QUALITY CONTROL

A1.0 INTRODUCTION

Environmental questions related to the development of the Kiggavik project by Urangesellschaft require high quality analytical data. This document presents a brief summary of the Quality Assurance/Quality Control (QA/QC) program in effect at Beak Analytical Services (BAS) and QC results specific to the Kiggavik project. As a source for many of its QA/QC policies, BEAK has relied heavily on such documents as EPA's Handbook for Analytical Quality Control in Water and Wastewater Laboratories (EPA-600/4-79-019) and a series of QA/QC publications produced by the Ontario Ministry of the Environment.

A1.1 Format

The QA/QC policies employed by BAS in the handling and analysis of Kiggavik samples are discussed under the separate categories listed below:

1. Chain of Custody Procedure/Sample Handling
2. Quality Assurance Procedures
3. Quality Control Procedures
4. Corrective Action
5. Performance Evaluation Audits

A2.0 CHAIN-OF-CUSTODY PROCEDURES AND SAMPLE HANDLING

Since the results of chemical analyses are often used to support litigation, the chain-of-custody of both samples and results is strictly controlled and documented. Following EPA guidelines, one person, Ms. Karen McMillan, is assigned the job of laboratory sample custodian and assumes custody of the samples on behalf of the laboratory.

The samples are preserved, if necessary, then logged into a computerized Laboratory Information Management System (LIMS). During log-in, each sample is assigned a unique, sequential identification number which is affixed to each sample. The laboratory custodian also enters the name of the person delivering the samples, the date and time of their receipt, the source of the sample (client), the type of sample, the condition of the sample, the parameters to be measured, whether or not the sample has been preserved and the sample storage location. The LIMS then generates an analysis sheet to be used at the laboratory bench. Samples are stored in an assigned location in the fridge or sample storage area. These areas, and indeed the laboratory itself, are accessible only to authorized personnel. Priority analyses such as pH are performed upon receipt of the samples.

The laboratory supervisor assigns the priority and the analyst to each chemical analysis of the sample. The analyst conducts the analysis and submits the results for entering into the LIMS. The raw data for each analysis are recorded in each analyst's bound notebook or in a parameter workbook. The LIMS generates a final report for the client. Final results, including the quality control data, are reviewed by the quality control officer or laboratory supervisor who authorizes release of the data to the project manager.

Once the sample analyses are completed, the unused portion of the sample, together with all identifying labels, are returned to the sample storage area. The returned samples are retained until permission to destroy the sample is received from the project manager or client, or the recommended maximum holding time has lapsed.

A3.0 QUALITY ASSURANCE PROCEDURES

The following sections are brief discussions on the measures and procedures taken at BEAK to ensure the high quality of results submitted to clients. Most of these measures are discussed in EPA (1979) and other QA/QC documents.

A3.1 Analytical Methods

All analytical methods used at BAS are clearly referenced, and are either identical, or very similar, to methods produced by standard-setting organizations such as the U.S. EPA, the Ontario Ministry of the Environment (MOE), APHA (Standard Methods) and Environment Canada. Any modifications to these methods such as changes in scale or concentrations are recorded in BEAK's Methods Manual.

A3.1.2 Methods Specific to Kiggavik Samples

Analysis of Kiggavik environmental samples has occurred over a ten-year period during which methodologies and analytical technologies have inevitably changed. Major changes to be noted include:

1. the automation of standard colorimetric analyses of nutrients; and
2. the introduction of graphite furnace atomic absorption spectrometry (GFAAS) for trace metal analysis.

Automation of the standard colorimetric analyses for ammonia, nitrate and phosphorus does not constitute a substantial change in methodology, since the same or similar chemical reactions are involved in the automated system as in the manual analysis. The graphite furnace, however, introduced in 1987 has permitted direct analysis of Kiggavik waters for trace metals at the parts per billion level without preconcentration. Previously, trace metal analyses were performed by direct current plasma emission spectrometry (DCP) or by flame atomic absorption spectrometry. Preconcentration was required to measure the low levels at which metals are found in these waters.

Instead of attempting to document detailed changes in methodology over the ten-year period, we will present the methodologies that were used in analysis of samples during 1987 and 1988. A summary of analytical methods are presented in Table A1. Specific conductance was measured on a calibrated Radiometer CDM83 conductivity meter using a CDC104 conductivity cell. Dissolved inorganic carbon (DIC) and dissolved organic carbon (DOC) were analyzed colormetrically (phenolphthalein indicator) on a Technicon auto analyzer. Alkalinity was measured titrametrically on a Radiometer VIT90 auto titrator. Phenols were determined colormetrically on a Technicon auto analyzer using the potassium ferricyanide method. Soluble reactive phosphorus was determined colormetrically (molybdate reaction) on a Technicon auto analyzer. Total phosphorus was also determined colormetrically after acid digestion of the samples in a hot block (Hames, 1983). Fluoride, sulphate and nitrate were determined by ion chromatography (Dionex 20001). Ammonia was analyzed colormetrically (nitroprusside method) on a Technicon IV auto analyzer. Total Kjeldahl nitrogen was determined colormetrically (salicylate-nitroprusside-hypochlorite) on a Technicon IV auto analyzer after acidic digestion. Total dissolved solids and total suspended solids were measured

TABLE A1: METHOD OF ANALYSIS OF EACH PARAMETER

Parameter	Matrix	Analysis
pH	Water	pH Meter
COD	Water/sediment	Dichromate Oxidation
Particle Size	Sediment	F.A.S.T., Pipette
Conductivity	Water	Conductance Cell
Hardness	Water	EDTA Titration
Total Suspended Solids	Water	Gravimetric
Total Nitrite-N	Water	Colorimetric-Sulfanilic Acid (manual)
Total Nitrate-N	Water	Ion Chromatography Dionex
Total Ammonia-N	Water	Colorimetric (automated - Technicon 4)
Total Phosphorus	Water	Colorimetric (automated - Technicon 4)
Cyanide	Water	Colorimetric-Pyridine-Pyrazolone (manual)
Arsenic	Water/sediment	Atomic Absorption/Hydride Generation
Copper	Water/sediment	Graphite Furnace A.A./DCP
Lead	Water/sediment	Graphite Furnace A.A./DCP
Zinc	Water/sediment	DCP
Mercury	Water/sediment	A.A./Cold Vapour (Perkin Elmer 430)
Cadmium	Water/sediment	Graphite Furnace A.A./DCP
Nickel	Water/sediment	Graphite Furnace A.A./DCP
Chromium	Water/sediment	Graphite Furnace A.A./DCP
Selenium	Water/sediment	A.A./Hydride Generation
Aluminum	Water/sediment	Graphite Furnace A.A./DCP
Silver	Water/sediment	Graphite Furnace A.A./DCP

gravimetrically. Chlorophyll samples were filtered through glass fiber filters in the field. The filters were frozen and returned to the laboratory for fluormetric analysis (Turner 430).

Alkali metals in Kiggavik waters were measured by DCP (Beckman Spectrospan V). Trace metals were determined directly by graphite furnace atomic absorption spectrometry (Perkin Elmer Zeeman 3030) with the exception of selenium, arsenic, mercury and zinc. Selenium and arsenic were analyzed by hydride generation on a dedicated Perkin Elmer 303 atomic absorption spectrophotometer (Standard Methods, 1985). Mercury was determined by the cold vapour flameless atomic absorption spectrometry (Hames, 1983). Because of problems encountered when analyzing zinc on our graphite furnace, zinc in water samples was analyzed by DCP. Despite the higher detection limits associated with the DCP relative to the graphite furnace, we were still able to meet the Water Board's requirement for detection limits for zinc (5 ppb).

Sediments for metals analysis were sieved through a non-contaminating screen and analyses were performed on the fine fraction (L 60 um). About 0.5 g (dry weight) was digested at 100^{o}C for 12 hours in 10 mL of aqua regia and diluted to 25 mL. Sediment extracts were analyzed by DCP with the exception of the hydrides (As and Se) and mercury. Analysis of mercury was performed on whole wet sediments to avoid loss of this volatile metal during drying.

Fish tissue (5 g) was digested in a mixture of 10 mL HNO_3, 2.5 mL perchloric acid and 1 mL of sulphuric acid at 110^{o}C for 12 hours. Fish samples were analyzed by graphite furnace with the normal exceptions (As, Se, Hg). Analytical methods used in the analysis of trace metals on animal and plant tissues collected in 1989 are presented in Appendix 1 of Supporting Document No. 3.

A3.2 Sampling Containers and Preservation

Selection of sample containers and sample preservation followed established QA/QC protocol. Sediment samples were collected in new, polyethylene "whirl-pac" bags. Water samples for general chemical parameters were collected in new 50 mL high-density polyethylene bottles. Samples for trace metals were collected in new 250 mL bottles of the same material after being soaked in acid for 24 hours and rinsed in distilled deionized water at least three times. Samples for trace metals were preserved in the field with "ultra" grade nitric acid. Separate samples were taken for mercury and were preserved with "ultra" grade nitric acid (1%) and potassium dichromate (5%). Priority analyses, including pH, conductivity and hardness, were conducted upon receipt of the samples. The samples were stored in an assigned location in the refrigerator at 4°C.

A3.2.1 Certification of Sampling Bottles

Checks are frequently run on sampling bottles as potential sources of contamination, especially in the analysis of trace metals. Sample bottles are tested by filling them with distilled, deionized water, adding the chemical preservative and allowing them to stand for periods of time up to three months. The results of these tests (Table A2) indicate that, within detection limits, BAS sampling bottles do not present a source of contamination to environmental samples.

A3.2.2 Reagents and Reagent Solutions

One of the major sources of anomalous results outside the limits of random error is contaminated reagents, or reagents which have been incorrectly prepared. Preventing these errors has become a major objective of our quality assurance program. All standards and reagents are prepared with chemicals which meet the American Chemical Society "anaytical reagent grade" standards. Special reagents are utilized for procedures requiring higher purity, such as "ultra grade" nitric acid in trace metals work. Purchased reagents are labelled with the date the bottle was opened. Reagents are not used past their date of expiration. Reagent solutions prepared in the laboratory are labelled with the date of preparation, the analyst who prepared the solution, the concentrations of active ingredients and an expiration date. Every effort is made to avoid contamination of reagents.

A3.2.3 Laboratory Water

The water used in preparation of reagents and in rinsing of glassware conforms to Type I water described in EPA (1979).

TABLE A2: CERTIFICATION OF SAMPLING BOTTLES FOR TRACE METAL ANALYSIS OF KIGGAVIK WATERS

Parameter	Lot 1 No. 1 (ppb)	Lot 1 No. 2 (ppb)	Lot 2 No. 1 (ppb)	Lot 2 No. 2 (ppb)	Three-Month Test (ppb)
Zinc	L 5	L 5	L 5	L 5	L 5
Cadmium	L 0.1	L 0.1	L 0.1	L 0.1	L 0.1
Copper	0.5	L 0.5	L 0.5	L 0.5	-
Lead	L 1	L 1	L 0.5	L 0.5	L 0.5
Chromium	-	-	L 1	L 1	-
Nickel	-	-	L 1	L 1	-
Aluminum	L 5	L 5	L 5	L 5	-
Mercury	-	-	L 0.05	L 0.05	-
Silver	-	-	L 0.1	L 0.1	-

A4.0 QUALITY CONTROL PROCEDURES

At BEAK Analytical Services (BAS), calibration, precision and accuracy during each analysis are controlled by:

- o calibration control standards,
- o in-run duplicates,
- o control standards,
- o recovery checks (spiking), and
- o performance evaluation audits.

These are discussed under separate sections below.

A4.1 Calibration Control

Following procedures promoted by the Ontario Ministry of the Environment, calibration is confirmed by means of two control standards A and B and a long-term blank which is made up and maintained independently of the calibration standards. The system is not calibrated with these solutions. The calibration control standards A and B are chosen to be about 70% and 20% of full-scale, respectively. The sums (A+B) and differences (A-B) are plotted versus time on a control chart and used immediately by the technician to determine whether the calibration process is in control. The warning and control limits are calculated from the standard deviation of the difference (MOE, 1976). Significant changes in sum (A+B) or difference (A-B) between runs indicates a change in slope or intercept, respectively. Examples of control charts for A-B and A+B are provided at the end of this appendix. An analytical run does not proceed unless statistical control of calibration is demonstrated.

A4.2 Control of Precision

The precision of each analysis at BAS is controlled by within-run duplicates of samples which are run at a frequency of 10%. Duplicate samples are completely separate samples subjected to the entire analytical procedure. The differences between duplicates are accumulated and sorted according to sample concentration ranges. For each range, control limits are calculated for the differences from the Shewhart formula:

$$UCL = 3.267 \times \bar{R} \quad \text{(ASTM, STP 15D)}$$

where UCL is the upper control limit and $\bar{R}$ is the mean difference between replicates. In general, except at the lower end of the scale, duplicate results should differ by less than 5%. Examples of control charts for differences between duplicates for Kiggavik parameters are found following (Section A6). Individual results of duplicate analyses are found in the data tables attached.

Duplicate results are also used to calculate the precision of the analysis for each concentration range. Precision is calculated as the coefficient of variation (standard deviation/mean) where the standard deviation is calculated from the formula:

$$D^2/2K$$

where D is the difference between duplicates and K is the number of duplicate pairs.

Estimates of precision are presented separately for sediment and water matrices in Tables A3 and A4. The applicable concentration range is indicated for each estimate. As to be expected for some analyses (for example, nickel in water), the coefficient of variation can be as high as 25 to 50%, close to the detection limit of the analysis.

A4.2.1 Detection Limits

As in many laboratories, BAS has traditionally reported detection limits which are based on a signal-to-noise ratio of 2.5. Concentrations less than these limits were reported as "less than" values. BAS is currently in the process of revising its determination of detection limits to be consistent with EPA and Ontario Ministry of the Environment regulations. These regulatory bodies advocate calculation of a method detection limit based on the standard deviation of within-run replicates and Students-t. A detection limit calculated in this way corresponds to the criterion of detection, which is defined as the concentration at which the probability is 5% of reporting an analyte which is not really present (ASTM, 1985). Table A5 presents detection limits in water reported at BAS by both methods. In general, detection limits reported in this study were based on the traditional signal-to-noise ratio. In the future, statistically determined Method Detection Limits will be provided based on the variability of replicates at the lower end of the concentration scale.

TABLE A3: PRECISION FOR WATER ANALYSES CALCULATED FROM REPLICATE DATA

Parameter	Analytical Method	Concentration Range	Precision as Coefficient of Variation (%)
Zn	DCP	0-50 ug/L	9.9
		50-1,000 ug/L	6.3
		GT 1,000 ug/L	3.4
Cd	GFAAS	0-1 ug/L	17
		1-2.5 ug/L	8.7
		GT 2.5 ug/L	4.1
Pb	GFAAS	1-10 ug/L	4*
		10-25 ug/L	3.1
Cr	DCP	L 50 ug/L	29
		50-1,000 ug/L	6.7
Ni	GFAAS	0-3 ug/L	54
	DCP	L 50 ug/L	11.5
		50-1,000 ug/L	9.1
Cu	GFAA	L 100 ug/L	5.1
Ca	DCP	1-20 mg/L	2.8
		20-50 mg/L	4.0
Al	GFAAS	0-20 ug/L	13.5
		20-40 ug/L	9.4
Mg	DCP	0.05-20 mg/L	4.2
		20-50 mg/L	1.3
K	DCP	1-5 mg/L	5.6
		5-12.5 mg/L	5.4
		12.5-25 mg/L	4.2
Na	DCP	0.5-20 mg/L	5.4
		20-50 mg/L	2.4
		50-100 mg/L	2.5
Hg	Cold Vapour A.A.	L 0.5 ug/L	27.3
		0.5-1 ug/L	12.1
		GT 1 ug/L	11.2
As	Hydride Generation	L 10 ug/L	10.7
		GT 25 ug/L	9.3

TABLE A3: PRECISION FOR WATER ANALYSES CALCULATED FROM REPLICATE DATA

Parameter	Analytical Method	Concentration Range	Precision as Coefficient of Variation (%)
Se	Hydride Generation	L 1 ug/L	42.3
		1-2 ug/L	23.3
Mn	DCP	L 0.1 mg/L	15.0
		0.1-1 mg/L	3.6
		GT 1 mg/L	2.1
Cu	DCP	1-20 mg/L	2.9
		20-50 mg/L	4.0
		50-100 mg/L	1.6
Al	DCP	0.05-1.0 mg/L	35.7
		1.0-5.0 mg/L	7.4
		5.0-20 mg/L	6.9
Conductivity	Conductivity Meter	0-100 us/cm	2.0
NH_3-N	Technicon 2	10-70 ug/L	10.8
NO_2-N	Colorimetric	1-15 ug/L	33.6
NO_3-N	Ion Chromatography	10-230 ug/L	11.5
		230-560 ug/L	5.9
Hardness	Titration	L 100 mg/L	2.2
TSS	Gravimetric	L 50 mg/L	18.2
Total Phosphorus	Technicon	0-20 ug/L	22.5
		50-100 ug/L	2.74
Cl	Ion Chromatography	0-10 mg/L	1.32
		10-50 mg/L	2.4
SO_4	Ion Chromatography	5-19 mg/L	0.8

* Provisional, based on only 3 to 5 points.

L = less than.

GT = greater than.

TABLE A4: ESTIMATES OF ANALYTICAL PRECISION FOR SELECTED SEDIMENT ANALYSES CALCULATED FROM REPLICATE DATA

Parameter	Analytical Method	Concentration Range (ug/g)	Precision as Coefficient of Variation (%)
Zn	DCP	L 50	3.6
Cr	DCP	L 50	3.6
		50-100	4.5
		GT 100	6.0
Ni	DCP	L 15	8.0
		15-20	3.7
		GT 50	1.17
Al	DCP		
Hg	Cold Vapour A.A.	L 0.5	27.3
		L 10	11.3
As	Hydride Generation	10-25	10.0
Se	Hydride Generation	L 1	42.3
		1-2	23.3

L - less than
GT - greater than

TABLE A5: DETECTION LIMITS FOR KIGGAVIK PARAMETERS BASED ON SIGNAL TO NOISE RATIO AND EPA's MDL's

Parameter	Matrix[1]	Signal: Noise	MDL
Conductivity	W	1.0 umhos/cm	0.265
TSS	W	2 mg/L	2.75
NO_2	W	0.001 mg/L	0.00042
NO_3	W	0.02 mg/L	0.011
NH_4	W	0.005 mg/L	0.0135
TP	W	0.002 mg/L	0.0014
TKN	W	0.05 mg/L	0.194
DOC	W	0.5 mg/L	0.114
Cyanide	W	0.002 mg/L	0.064
As (Hydride)	W	1 ug/L	2.46
	S	0.5 ug/g	
Cu (GFAAS)	W	0.5 ug/L	6.4
(DCP)	S	1 ug/g	
Pb (GFAAS)	W	0.5 ug/L	1.09
(DCP)	S	1 ug/g	
Zn (DCP)	W	5 ug/L	10.2
	S	1 ug/g	
Hg (CVAAS)	W	0.02 ug/L	0.0565
	S	0.02 ug/g	
Cd (GFAAS)	W	0.1 ug/L	0.0578
	S	0.05 ug/g	
Ni (DCP/GFAAS)	W	1 ug/L	5.6/-
(DCP)	S	1 ug/g	
Cr (DCP/GFAAS)	W	10/1 ug/L	8.7/-
(DCP)	S	1 ug/g	

TABLE A5: DETECTION LIMITS FOR KIGGAVIK PARAMETERS BASED ON SIGNAL TO NOISE RATIO AND EPA's MDL's

Parameter	Matrix[1]	Signal: Noise	MDL
Al (DCP/GFAAS)	W	20/5 ug/L	16/-
(DCP)	S	5 ug/g	
Ag (GFAAS)	W	0.1 ug/L	-
(DCP)	S	0.5 ug/g	
Se (Hydride)	W	0.1 ug/L	0.96
	S	0.5 ug/g	-

[1] W = water; S = sediments.

A4.3 Accuracy

BAS uses standard reference materials whenever available as a check on the accuracy of each analytical run. Because of the low level of some of the parameters (especially the metals) in Kiggavik waters, some of the reference water used at BAS required dilution to be run on-scale with the samples. Recognizing this general problem, BAS is developing its own low-level reference standards as a check on accuracy. Internal reference standards have been established for a variety of water parameters, including nitrite, nitrate, total phosphorus, chromium and copper. In addition, a low-level sediment standard was created from dried, milled sediments from Dyke Lake, N.W.T. Samples of this sediment are run with all low-level sediment samples and results are accumulated for control charting.

Tables A6 and A7 present the results for analyzing standard reference materials for both water and sediments. When available, control limits, based on our historic data, are also included in the table to demonstrate that accuracy was under control during analysis of Kiggavik samples. Examples of control charts with warning limits set at ± two standard deviations and control limits set at ± three standard deviations are presented in the figures following. Table A8 presents the results of analyzing standard reference materials with the fish tissue samples.

A4.4 Recovery Checks

In methods where digestion and extractions are required, recovery checks or spikes are used to estimate the efficiency of the analysis. The percent recovery is estimated as:

$$\% \text{ Recovery} = \frac{\text{Measured Value}}{\text{Theoretical Value}}$$

Recoveries of less than 85% and greater than 115% are deemed unacceptable in most analyses and appropriate corrective action is taken. Examples of spike recoveries of the analysis of fish tissue are presented in Table A8.

TABLE A6: SUBSET OF STANDARD REFERENCE MATERIALS USED IN ANALYSIS OF KIGGAVIK WATERS

Parameter	Reference Material	True Value	Analyzed Value	Control Limits[1]
DIC	Internal QCB	16.0	16.0, 15.8	13.39-17.41
DOC	Internal QCB	9.0	9.2, 9.0	8.3-10.1
Colour	Internal QCB	20	20	19.4-20.6
TKN	Internal QCB	0.50	0.52	0.421-0.565
TP	Internal QCB	0.025 mg/L	0.026	0.018-0.030
As	WP386	100 ug/L	100	85-112
Cu (G.F.)	WP386	100 ug/L	109	82.9-127.2
Pb (G.F.)	WP376	100 ug/L	98	-
Zn (DCP)	WP386I	100 ug/L	107	79.8-142
Hg	WP1183	4.7 ug/L	4.7	3.4-5.8
Cd (G.F.)	WP378 #14	5.0 ug/L	5.05	4.67-5.82
Ni (G.F.)	WP386	100 ug/L	99.2, 104	89.0-112
Cr (G.F.)	WS378 #4	13 ug/L	14.1, 14.3	11.8-16.9
Se	WP386	25 ug/L	21	17.3-28.1
Al (G.F.)	WP386	500 ug/L	518, 502	400-635
Ca (DCP)	WP686	5.0 mg/L	5.0	4.42-5.42
Mg (DCP)	WP686	0.50 mg/L	0.523, 0.534	-
K (DCP)	WP686	1.0 mg/L	1.07	0.95-1.41
Na (DCP)	WP1185	20.0 mg/L	19.7	18.5-20.5

[1] Based on BAS historic data.

TABLE A7: STANDARD REFERENCE MATERIALS USED IN ANALYSIS OF KIGGAVIK SEDIMENTS

Parameter	Reference Material	True Value (ug/g)	Analyzed Value (ug/g)	Control Limits (ug/g)
Ca**	BCSS-1	$5.43x10^3$	$4.10x10^3$	$3.25-4.40x10^3$
Al**	BCSS-1	$6.26x10^4$	$1.73x10^4$	-
Mg**	BCSS-1	$1.47x10^4$	$1.01x10^4$	$1.05x10^3-1.28x10^4$*
Zn	BCSS-1	119	113	96-138*
Cd	BCSS-1	0.25	L 1	0.21-0.29
Mn	BCSS-1	229	210	188-235*
Co	BCSS-1	11.4	12	11.8-14.5*
Cu	BCSS-1	18.5	18	15.2-21.0*
Pb	BCSS-1	22.7	21	19.3-26.1
Cr**	BCSS-1	123	57	50.4-68.9*
Ni	BCSS-1	55.3	53	51.7-58.9
Se	BCSS-1	0.43	L 0.5	-
As	BCSS-1	11.1	10.2	9.7-12.5
COD	WP784	156	145	-

* Control limits based on BEAK's historic data. Remaining control limits represent the certified values ± 95% confidence interval.

** Metals underestimated because of choice of extraction procedure.

TABLE A8: SPIKED RECOVERIES AND RESULTS OF ANALYZING STANDARD REFERENCE MATERIAL (EPA TRACE METALS IN FISH) WITH FISH TISSUE SAMPLES

Parameter	Spike Recovery (%)	SRM (ug/g)	Certified Value[1] (ug/g)
Cadmium	97	0.403	0.16±0.16
Mercury	103	2.60	2.52±1.28
Arsenic	87.5	3.6	2.43±1.58

[1] Certified values expressed as 95% confidence interval.

A4.5 Corrective Action for a System Out-of-Control

In applying control charts, loss of control is indicated by a point beyond the control limit. If control limits are exceeded for a particular analysis, subsequent analyses are halted until the system is checked and determined to be in-control again. Results are not released to clients unless the system has been declared in control by the quality control officer.

A4.6 Performance Evaluation Audits

BEAK has participated and continues to participate in a large number of external audits. The audits involve the analysis of check standards or interlaboratory comparisons of samples conducted by various government agencies. The results of these external audits are available on request. In addition, BEAK is certified for doing work under EPA regulations in New York (Certificate No. 10823). This certification requires BAS to undergo routine proficiency testing and laboratory inspection. BEAK also acts as a private contract laboratory to the Ontario Ministry of the Environment in the Ministry's Inland Lakes Program. This program involves extensive quality control checks of the data produced by Beak Analytical Services.

The following is a summary of the External Performance audits in which we have participated:

Environment Canada Canada Centre for Inland Waters Burlington, Ontario (1975-1989)	<u>The National Interlaboratory Quality Control Program</u> Continued participation since 1975. Studies 14, 15, 16, 18, 19, 20, 21, 23, 25, 27, 28, 29, 30, 33, 35, DQC-2, DQC-3, LRTAP9, 10, 11, 12, 15, 16, 17, 18, 19, 20, 21, QM3, 4, 5, 9, 11 and 12.
Environment Canada Fisheries and Oceans Captine Bernier Laboratories Longeuil, Quebec	<u>Project Analytical Cross-Check Program</u> Interlaboratory comparison of mercury, cadmium, copper, lead, selenium and zinc in fish tissue in 1977. Interlaboratory comparison of cadmium, mercury, lead and PCBs in sediment and biological material in 1980.

Environment Canada Environmental Protection Service Bedford Institute of Oceanography	<u>Project Analytical Cross-Check Program</u> Interlaboratory comparison of mercury, cadmium, copper and PCBs in sediment and biological material in 1980. Quality control check for PCBs, chlorobenzenes and PAHs in standards and spiked sediment.
Ontario Ministry of the Environment Environmental Laboratory Services Branch Toronto, Ontario	<u>Leachate Analysis Comparative Study, 1985</u> Interlaboratory comparison of five industrial waste samples using the MOE Leachate Procedure (LP) for recovery of Cd, Cu, Cr, Mn, Ni, Pb and Zn.
National Research Council of Canada Ottawa, Ontario	<u>Marine Analytical Chemistry Standard Program First Intercomparison Exercise for Trace Metals in Marine Sediments - NRC MS1/TM</u> Calibration for Cu, Zn, Cd, Hg and Pb in 1984.
Energy, Mines and Resources Earth Sciences Geological Survey of Canada Ottawa, Ontario	<u>Canadian Certified Reference Materials Project, 1984</u> Collaborative testing of four stream sediments for Hg, Cd, Cu, Cr, Fe, Ni, Pb and Zn.
Noranda	Interlaboratory Study 1989
Ministry of the Environment	Interlaboratory Studies 89-5 and 89-6 for MISA Program

A4.6.1 Cross-Check of BAS Analyses with the NAP Water Laboratory

An interlaboratory cross-check between BAS and the NAP Water Laboratory of analytical results was conducted during June 1988 on replicate samples taken at three stations for Neptune Resources. In total, four replicate samples were taken from each station, three being analyzed at BAS as replicates and the fourth sent to the NAP Water Laboratory for comparison. The results shown in Table A9 indicate that, for all parameters, very similar results were produced in both laboratories.

A5 Radiochemical Analyses

A5.1 Water Samples

Water samples were collected from Kiggavik as 180 L volumes of unfiltered water. Samples were acidified to pH 2-3 with concentrated H_2SO_4 (1988) or HNO_3 (1989) in 70-

TABLE A9: CROSS-CHECK OF ANALYSES OF WATER SAMPLES AT BAS BY THE NAP WATER LABORATORY

	Baton Main (Subsurface)				Baton North (Subsurface)				Tailings Creek			
	1	2	3	NAP	1	2	3	NAP	1	2	3	NAP
pH	7.70	7.50	7.55/7.55	7.3	7.60	7.65	7.60	7.6	7.30	7.30	7.30	7.4
Conductivity (umhos/cm)	97	97	97	94	98	96	97/97	94	99	100	99	95
Suspended Solids (mg/L)	L 5	L 5	L 5/L 5	L 2	7	L 5	L 5	L 2	L 5	5	L 5	L 2
Total Hardness (mg/L as $CaCO_3$)	46	44	46/46	46	46	48	48	46	48	48	48	48
Ammonia-N (mg/L)	0.025	0.015	0.015	0.018	0.020	0.010	0.010	0.008	L 0.005	L 0.005	L 0.005	0.009
Nitrite-N (mg/L)	0.001	0.001	L 0.001	L 0.04	L 0.001	L 0.001	L 0.001	L 0.04	L 0.001	L 0.001	L 0.001	L 0.04
Nitrate-N (mg/L)	L 0.01	L 0.01	L 0.01	L 0.04	L 0.01	L 0.01	L 0.01	L 0.04	L 0.01	L 0.01	L 0.01	L 0.04
Total P (mg/L)	0.005	0.005	0.010	0.008	0.005	0.004	0.004	L 0.005	0.003	0.003	0.004	L 0.005
Total Cyanide (mg/L)	L 0.002	L 0.002	L 0.002	L 0.005	L 0.002	L 0.002	L 0.002	L 0.005	L 0.002	L 0.002	L 0.002	0.006
Zn (ug/L)	L 5	L 5	L 5	L 1	L 5	L 5	L 5	L 1	L 5	L 5	L 5	L 1
Cd (ug/L)	0.1	0.1	0.2	0.5	0.3	0.1	0.1	L 0.5	0.2	0.1	0.1	L 0.5
Cu (ug/L)	0.5	1	0.5	L 1	0.5	0.5	1.0	L 1	0.5	0.5	L 0.5	L 1
Pb (ug/L)	L 0.5	L 0.5	0.5	L 1	L 0.5	L 0.5	L 0.5	L 1	0.5	0.5	0.5	1
Cr (ug/L)	1	L 1	L 1	L 1	1	1	L 1	L 1	L 1	L 1	L 1	L 1
Ni (ug/L)	L 1	L 1	L 1	L 1	1	L 1	L 1	L 1	L 1	L 1	L 1	L 1
Al (ug/L)	10/10/15	15	10	-	15	25	10	-	10	10	10	-
Hg (ug/L)	L 0.05	L 0.05	L 0.05	L 0.02	L 0.05	L 0.05	L 0.05	L 0.02	L 0.05	L 0.05	L 0.05	L 0.02
Se (ug/L)	L 0.1	L 0.1	L 0.1	-	L 0.1	L 0.1	L 0.1	-	L 0.1	L 0.1	L 0.1	-
As (ug/L)	L 1	L 1	L 1/L 2	L 1	L 1	L 1	L 1	L 1	L 1	L 1	L 1	2
Ag (ug/L)	L 0.1/L 0.1	L 0.1	L 0.1	-	L 0.1	L 0.1	L 0.1	-	L 0.1	L 0.1	L 0.1	-
Fe (ug/L)	-	-	-	16	-	-	-	26	-	-	-	7

Note: Multiple entries for individual parameters and samples represent laboratory replicates.

L - less than detection limit

L plastic garbage pails. Tracers were added for Th (Th-234), Ra-226 (Ba-133) and Pb-210 (stable Pb or Pb-203). To each sample, 2 g of Fe^{2+} was added (as $FeSO_4$ in 1988, and as $FeCl_3$ in 1989). To aid in scavenging of radium from the sample, $BaCl_2$ (1988) or $Ca_3(PO_4)_2$ was also added. After an equilibration period, the pH was adjusted to about 9 by the addition of NaOH. The samples were stirred for about one minute and allowed to settle for at least one hour. The supernatant was then siphoned off and the iron floc collected in 4-L "Nalgene" bottles. Samples were subsequently shipped to the laboratory for further concentration by centrifugation, and were then dried at about 70°C.

Field tracers for uranium were unavailable at the time of the 1988 field campaign. Uranium yields were estimated as the average recovery from three Kiggavik Lake water samples each spiked with 193.4 mg of natural uranium from a standard solution and otherwise treated like the samples described above. The average uranium recovery of 53.6% (range 45.8 to 59.1%) was assumed to apply for uranium in iron precipitates from all 1988 water samples. In 1989, acidified whole water samples (2 L) were submitted for analysis, as it was felt that the required detection limit could be obtained by delayed neutron activation analysis of uranium recovered from an unconcentrated sample of this volume.

Recoveries of Th-234, Ba-133 and Pb-203 were determined by Becquerel Laboratories Inc. of Mississauga, Ontario using gamma spectroscopy. Recovery of stable Pb was determined by Beak Analytical Services using plasma emission spectroscopy of a subsample of the iron precipitate.

For measurement of uranium, an aluminum tracer was added to an acidified sample and aluminum 8 hydroquinolate was used to precipitate the uranium. As well, thorium would be precipitated by this solid. The solution pH was adjusted to a pH of 6 to 7, and the precipitate filtered. Then, uranium and thorium were determined by neutron activation analysis of the sample collected on the filtered disk and compared with standards composed of spike solutions of uranium and thorium.

For analysis of Th-232, -230 and -228, the yield tracer Th-234 had been added originally to the 50 to 100 L aliquot of water and the thorium isotopes precipitated with a hydroxide precipitate. Nitric acid was added to the precipitate, which dissolved all of the residue and filtered material. This solution then passed through an ion exchange column after additional nitrate was added. The thorium nitrate (negatively-charged complex) stayed on the column, whereas other isotopes passed through. The solution passing through the column contained mainly iron, which washed clear through the column. To further clean up the thorium-containing solution, additional steps were carried out. The column was elutriated using 10 to 20 mL of 3% sulphuric acid and then the thorium was separated by use of 50 ug of lanthanium added to 1 mL of hydrochloric acid. The lanthanium fluoride (LaF_3) precipitate, which carries the thorium fluoride (ThF_4) precipitate, was then filtered through 0.22 micron filters and used for alpha counting, after counting the precipitate content of Th-234 to give an overall estimate of yield all the way from the initial addition of Th-234 to the 60 to 180 L aliquot to the amount of Th contained (Th-234) in the precipitate.

Lead-210 activities in the iron precipitates were determined indirectly, by alpha spectroscopy of the Po-210 decay daughter, by Chalk River Nuclear Laboratories, Chalk River, Ontario. The original Po-210 is volatilized from the sample and Po-210 allowed to in-grow from its Pb-210 parent. The Po-210 daugher is then counted, and the Pb-210 activity determined after decay correction. The method is documented in Cornett et al. (1984).

In 1988, Ra-226 was analyzed by Saskatchewan Research Council using the radon emanation method. Ra-226 was brought into solution using an EDTA carrier, and radon activity counted by alpha spectroscopy. In 1989, Ra-226 was measured by alpha spectroscopy.

A5.2 Sediments

All surficial sediment samples from Kiggavik were analyzed for radionuclide content by Monenco Analytical Laboratories, Calgary, Alberta. Solids from the groundwater seeps were analyzed by Becquerel Laboratories, Mississauga, Ontario.

Prior to analysis of radionuclide concentrations or activities, lake sediments were dried at 50°C and ground to ensure sample homogeneity. Samples for Ra-226 and Th isotope analyses were dissolved by KF-pyrosulphate fusion. Samples for total U, Pb-210 and Po-210 analyses were digested in a hot, concentrated mixture of HNO_3, $HClO_4$ and HF, followed by a pyrosulphate fusion.

The methods used for radionuclide analysis are detailed in Chiu and Dean (1984) for U, Th isotopes, Ra-226 and Pb-210 and in Smithson (1979) for Pb-210. Total U in the solution was determined fluorometrically as its fluoride complex following fusion with NaF-LiF. Th isotopes were determined using high-resolution alpha spectrometry (HRAS). Prior to analysis, Th-234 was added to the digested sample as a tracer. Th was coprecipitated with $PbSO_4$, isolated by solvent extraction, and then coprecipitated with cerous hydroxide. The precipitate was beta-counted for Th-234 to measure the overall yield and then Th-230, Th-232 and Th-228 measured by HRAS. Ra-226 was determined by HRAS using Ba-133 as a tracer. Ra was coprecipitated with $BaSO_4$, and the chemical yield measured by gamma counting of Ba-133. Pb-210 was measured indirectly using Bi-210. The sample solution was held for 30 days prior to analysis to permit greater than 98% ingrowth of Bi-210. A carrier solution of stable Pb and Bi was added before digestion. Bi was then solvent extracted, precipitated as BiOCl, and Bi-210 measured by beta-counting. Po-210 was measured by HRAS using Po-208 as a tracer. Po isotopes were deposited on a nickel disc and the yield measured by recovery of the tracer. Radiochemical determinations were also carried out on one or two UTS reference standards, developed for the National Uranium Tailings Program, Department of Energy, Mines and Resources Canada, for every 15 to 20 sediment samples analyzed.

Sediment core slices were analyzed for Pb-210 content by Chalk River Nuclear Laboratories.

The concentration of Pb-210 is determined by measuring the activity of its decay daughter, Po-210, using alpha spectroscopy, using a modified version of the technique of Eakens and Morison (1977), as reported by Cornett et al. (1985).

Groundwater solids collected in 1989 were measured by direct gamma spectroscopy. Total uranium concentrations were assumed to equal the activity concentrations of Th-234. Ra-226 activities were measured by determining activities of Pb-214 and Bi-214. Lead-210 levels were measured directly. Levels of Th-230 were measured directly in the Main Zone sample, but required alpha spectroscopy for quantification in the reference site sample, as described above for lake sediments. No Po-210 analyses were completed on these solids samples.

A5.3 Fish Tissues

Fish flesh samples were composited and homogenized in a blender. Fish bone samples (headless skeletons) were separated from the carcass in hot water, and were subsequently crushed and composited. Aliquots of about 0.5 g of flesh or bone were then digested in acid and radiochemical determinations carried out as described for surficial sediments. Radiochemical determinations were carried out by Monenco Analytical Laboratories in 1988.

A6 References

ASTM. 1985. ASTM Standards on Precision and Bias for Various Applications. ASTM, Philadelphia, PA. 256 p.

Chiu, N.W. and J.R. Dean. 1984. Analytical Methods Manual, National Uranium Tailings Program. A Report by Monenco Consultants Limited for Energy, Mines and Resources Canada.

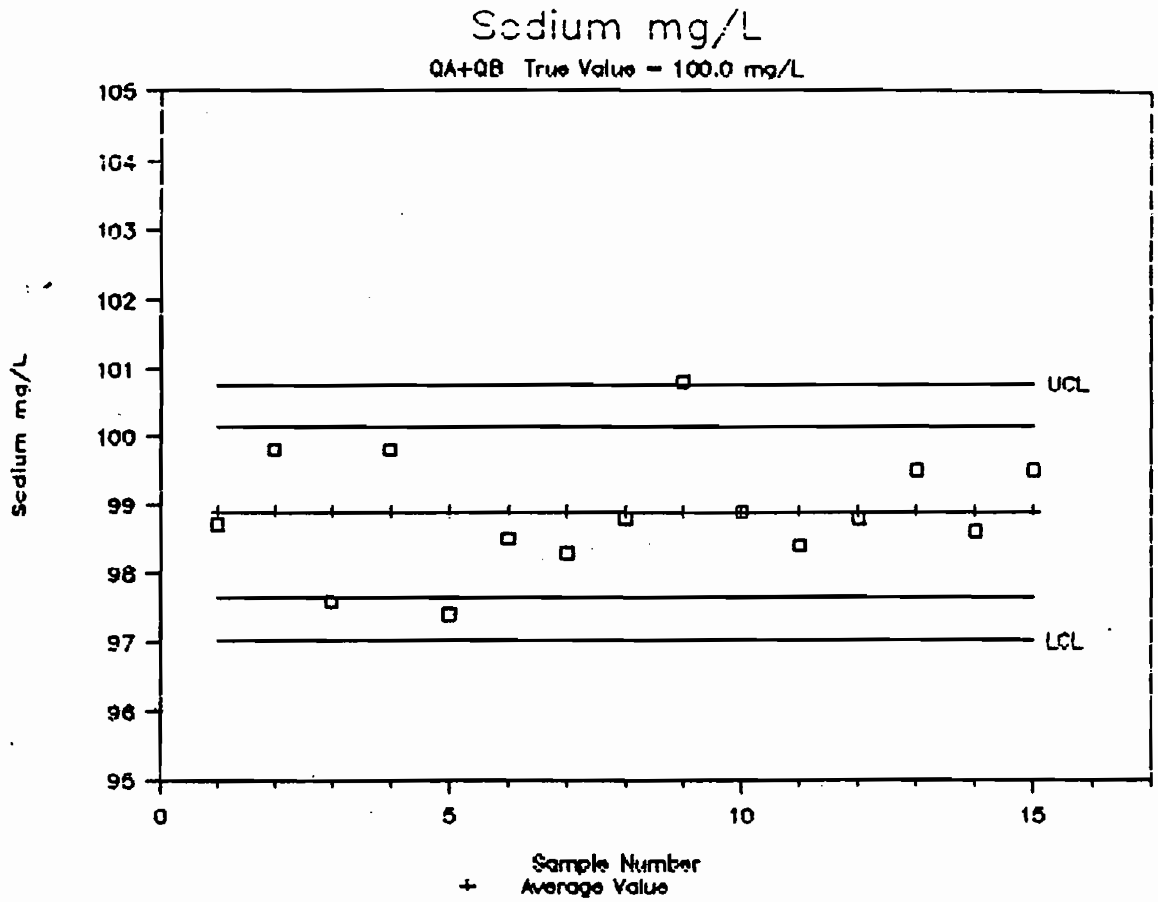
HAMES. 1983. Handbook of Analytical Methods for Environmental Samples. Ontario Ministry of the Environment.

Ontario Ministry of the Environment (MOE). 1976. Quality Control and Data Evaluation Procedures. Laboratory Services Branch, Data Quality Report Series Appendix.

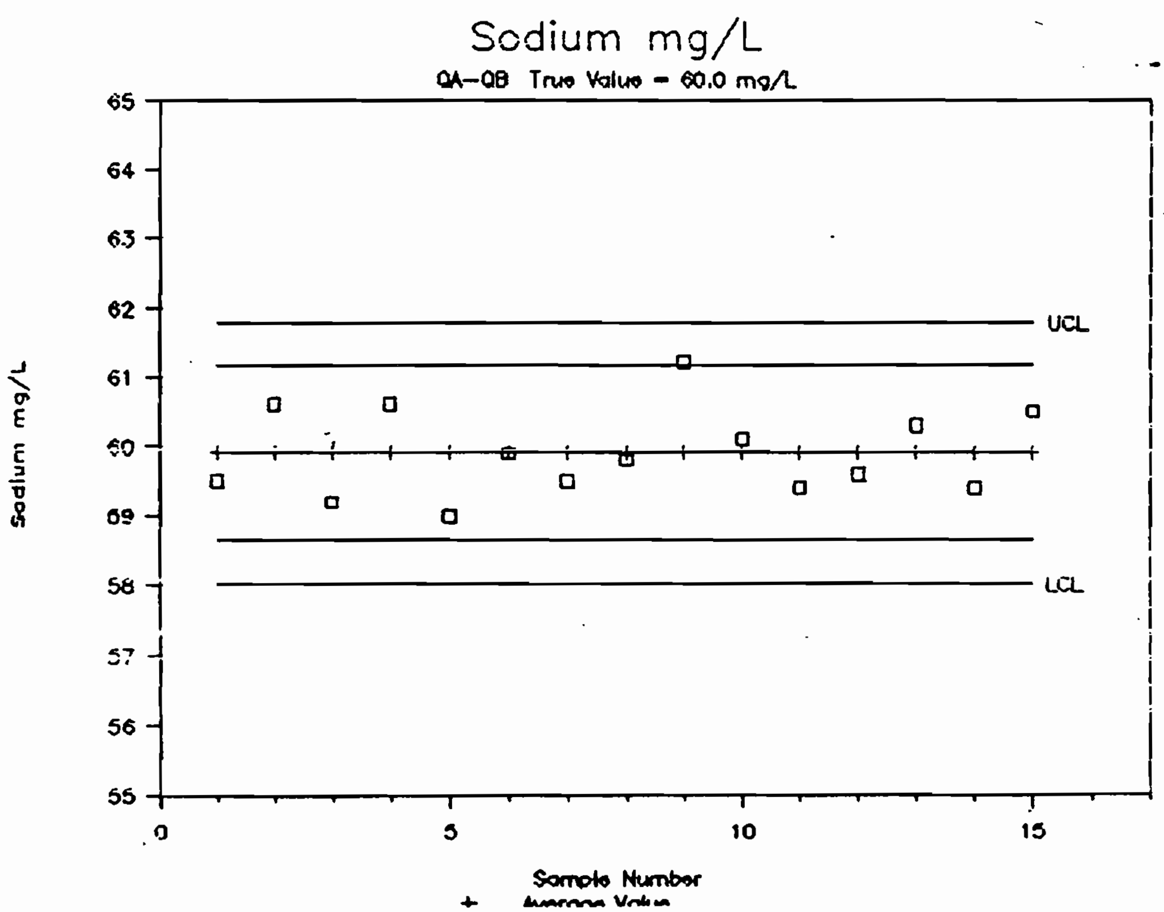
Smithson, G.G. 1979. Radiochemical procedures for determination of selected members of the uranium and thorium series. CANMET Rep. 78-22.

U.S. Environmental Protection Agency (EPA). 1979. Handbook for Analytical Quality Control in Water and Wastewater Laboratories. EPA-600/4-79-019.

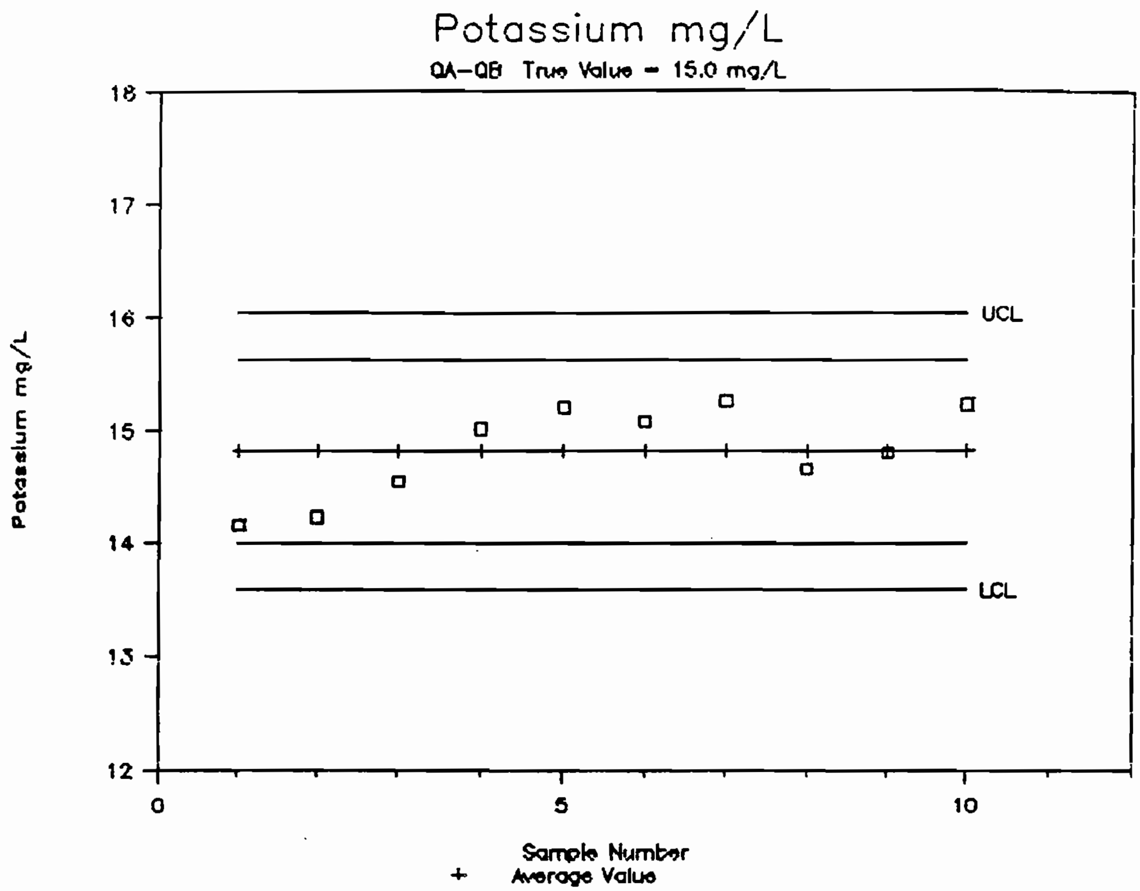
Selected Examples of Calibration Control Charts for Kiggavik Analyses



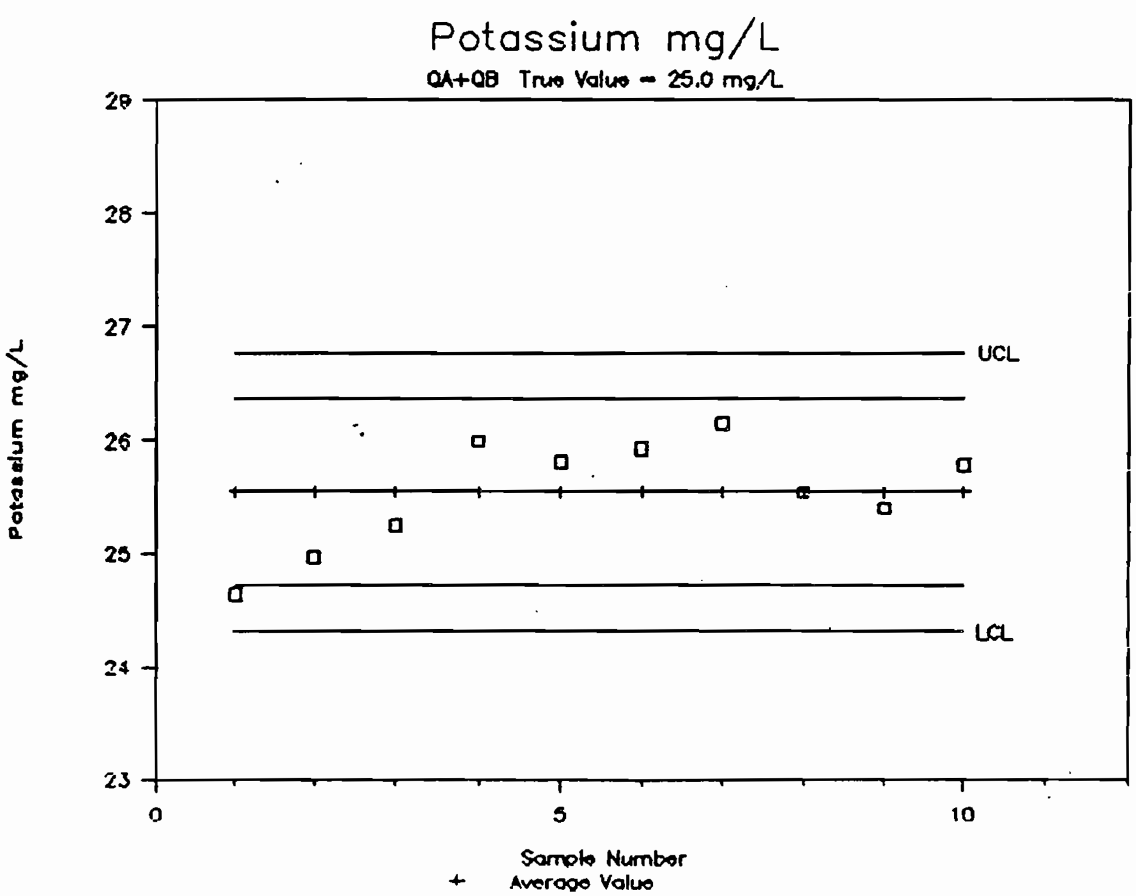
Sodium mg/L
QA+QB True Value = 100.0 mg/L
105
104
103
102
101
100
99
98
97
96
95
Sodium mg/L
UCL
LCL
0
5
10
15
Sample Number
+ Average Value



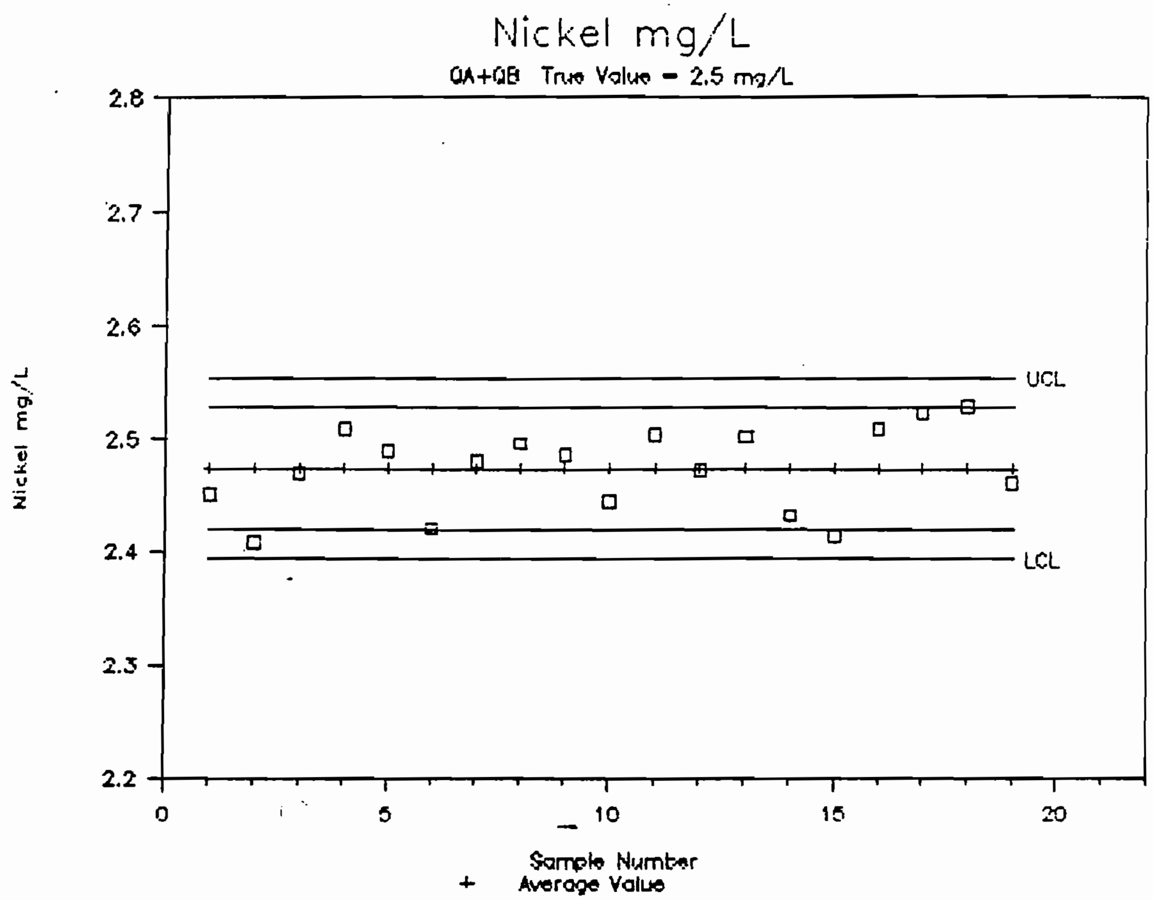
Sodium mg/L
QA-QB True Value = 60.0 mg/L
65
64
63
62
61
60
59
58
57
56
55
Sodium mg/L
UCL
LCL
0
5
10
15
Sample Number



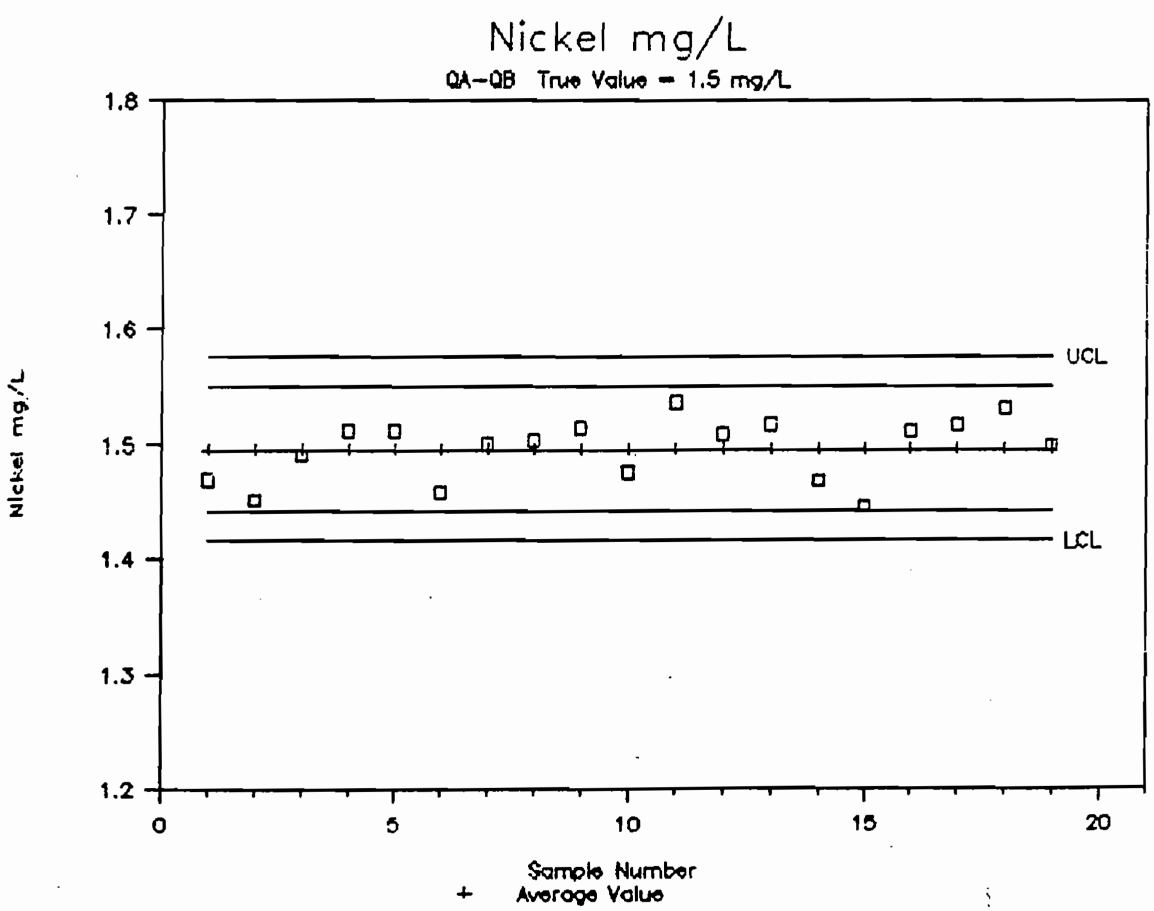
Potassium mg/L
QA-QB True Value = 15.0 mg/L
18
17
16
15
14
13
12
UCL
LCL
Potassium mg/L
0
5
10
Sample Number
+ Average Value



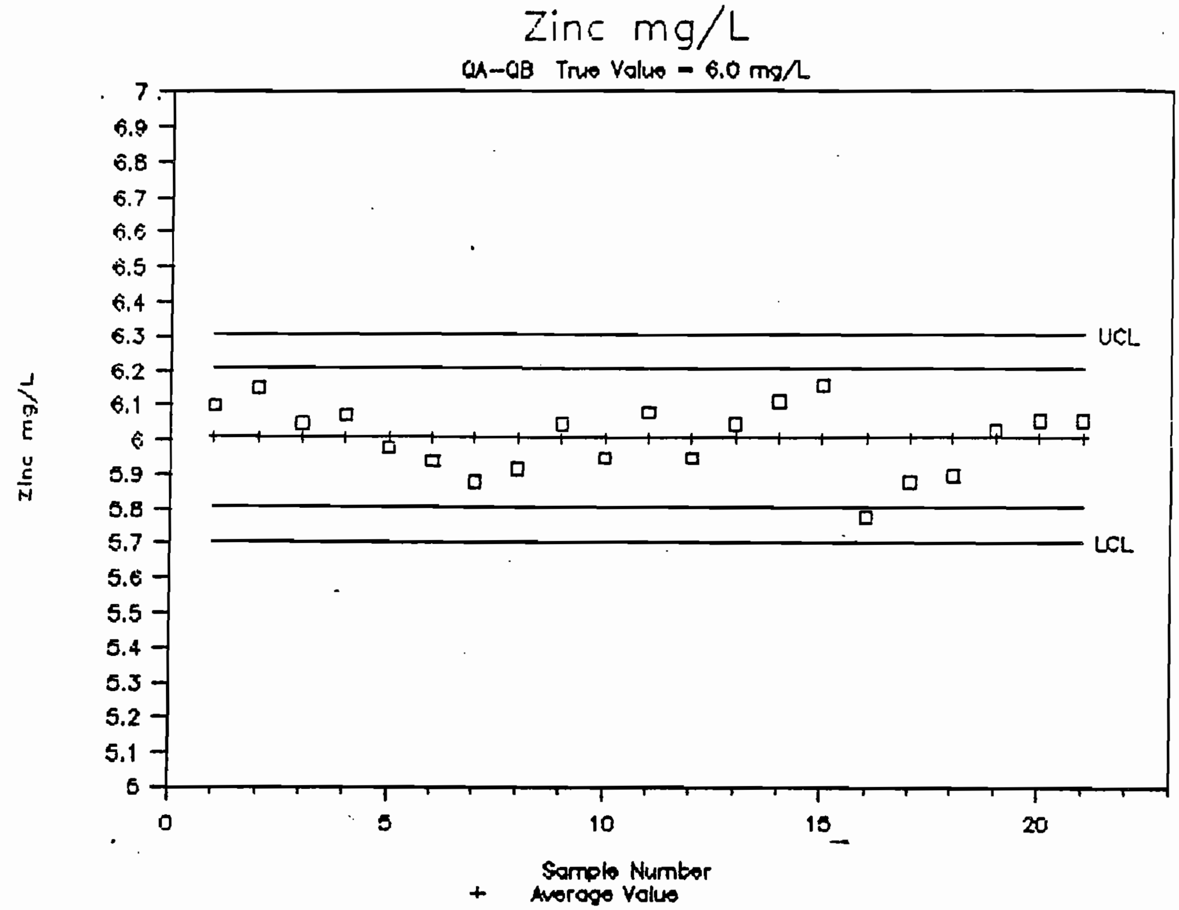
Potassium mg/L
QA+QB True Value = 25.0 mg/L
29
28
27
26
25
24
23
UCL
LCL
Potassium mg/L
0
5
10
Sample Number
+ Average Value

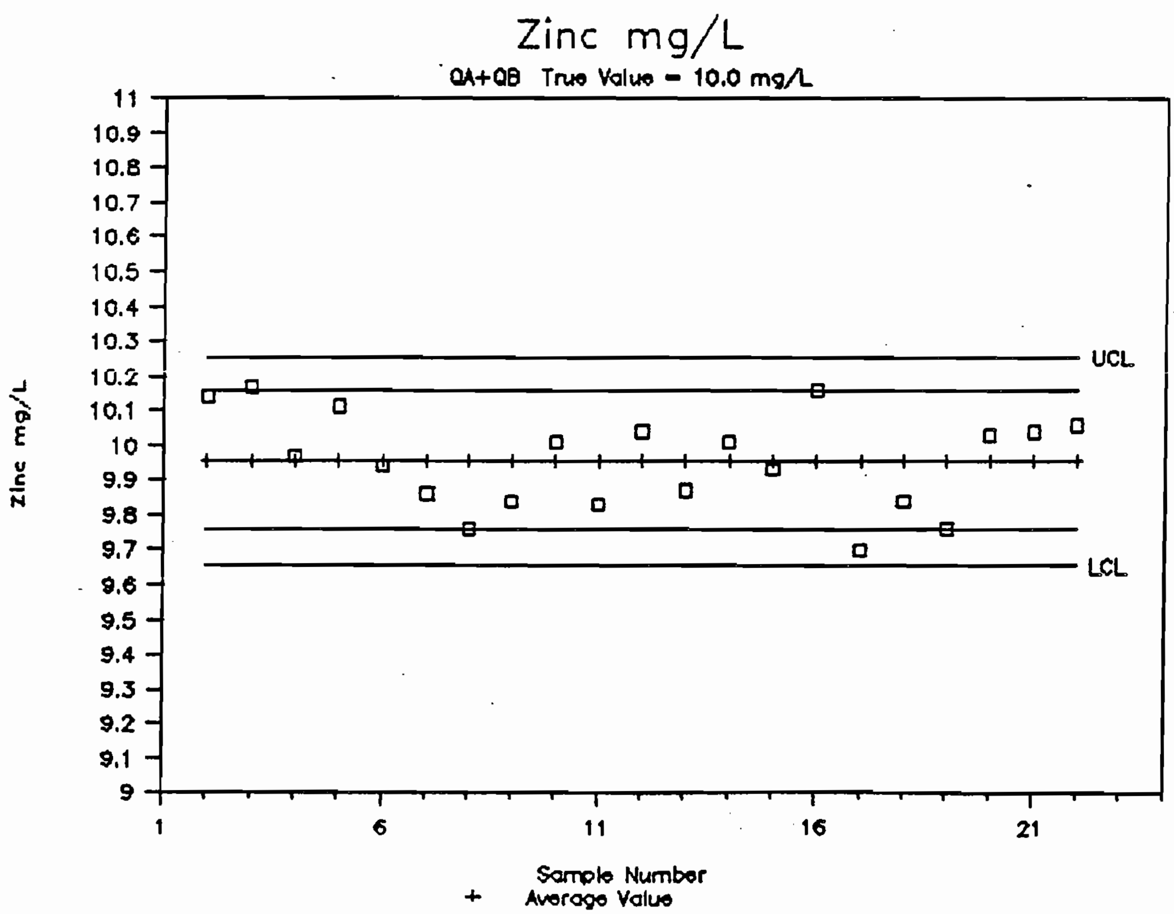


Nickel mg/L
QA+QB True Value = 2.5 mg/L
Nickel mg/L
UCL
LCL
Sample Number
+ Average Value

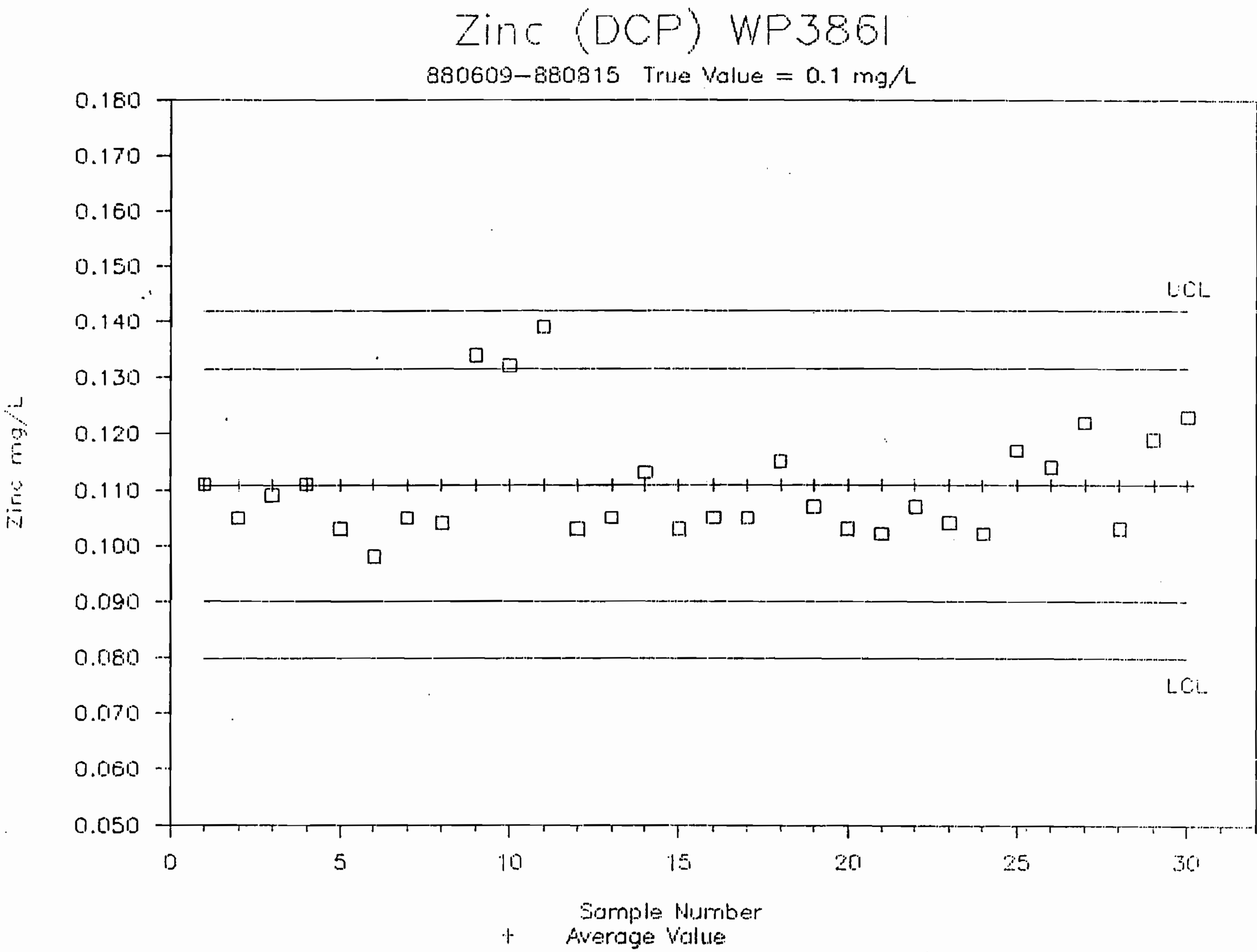


Nickel mg/L
QA-QB True Value = 1.5 mg/L
Nickel mg/L
UCL
LCL
Sample Number
+ Average Value

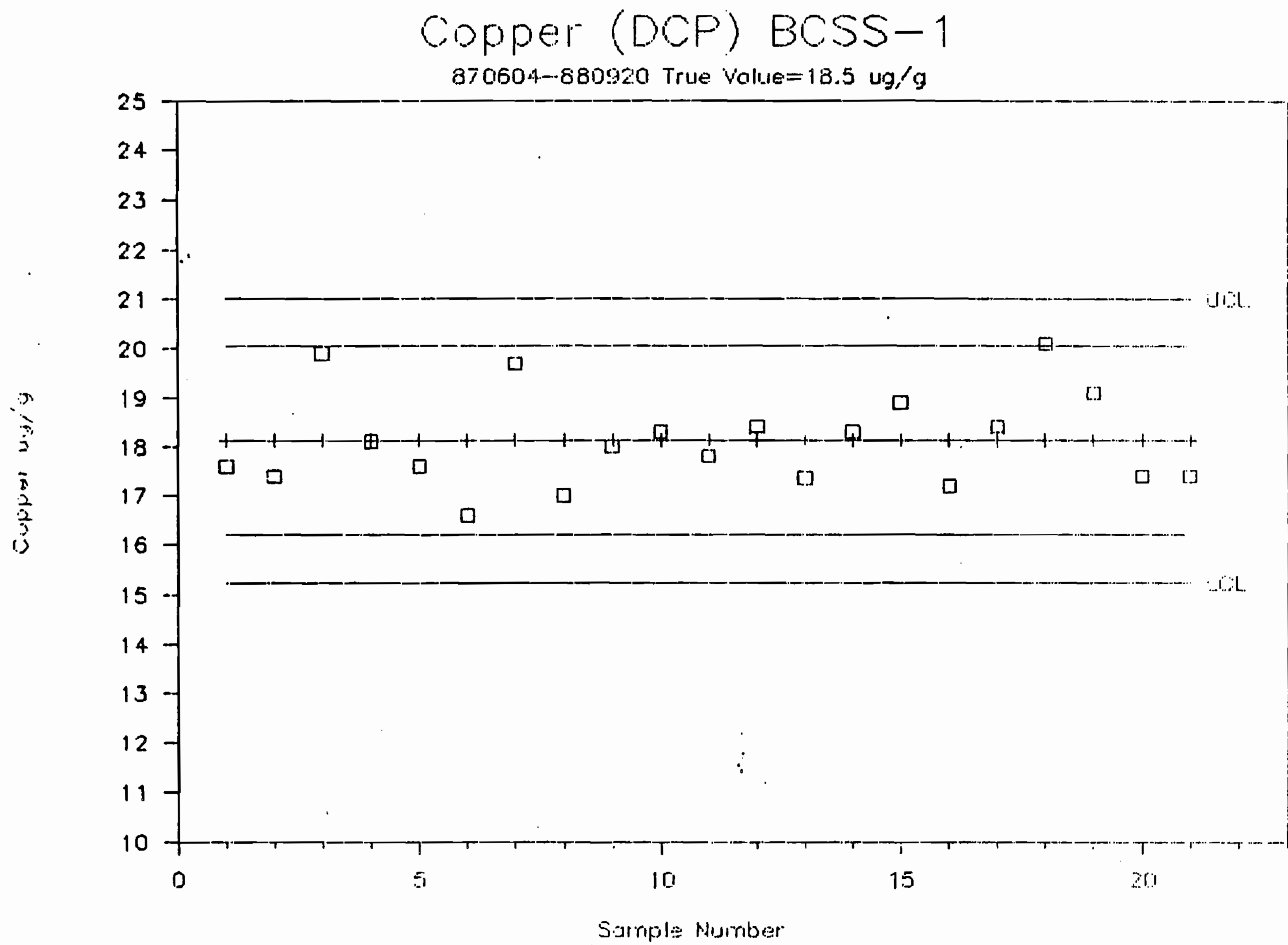

Zinc mg/L
QA-QB True Value = 6.0 mg/L
UCL
LCL
Zinc mg/L
Sample Number
+ Average Value

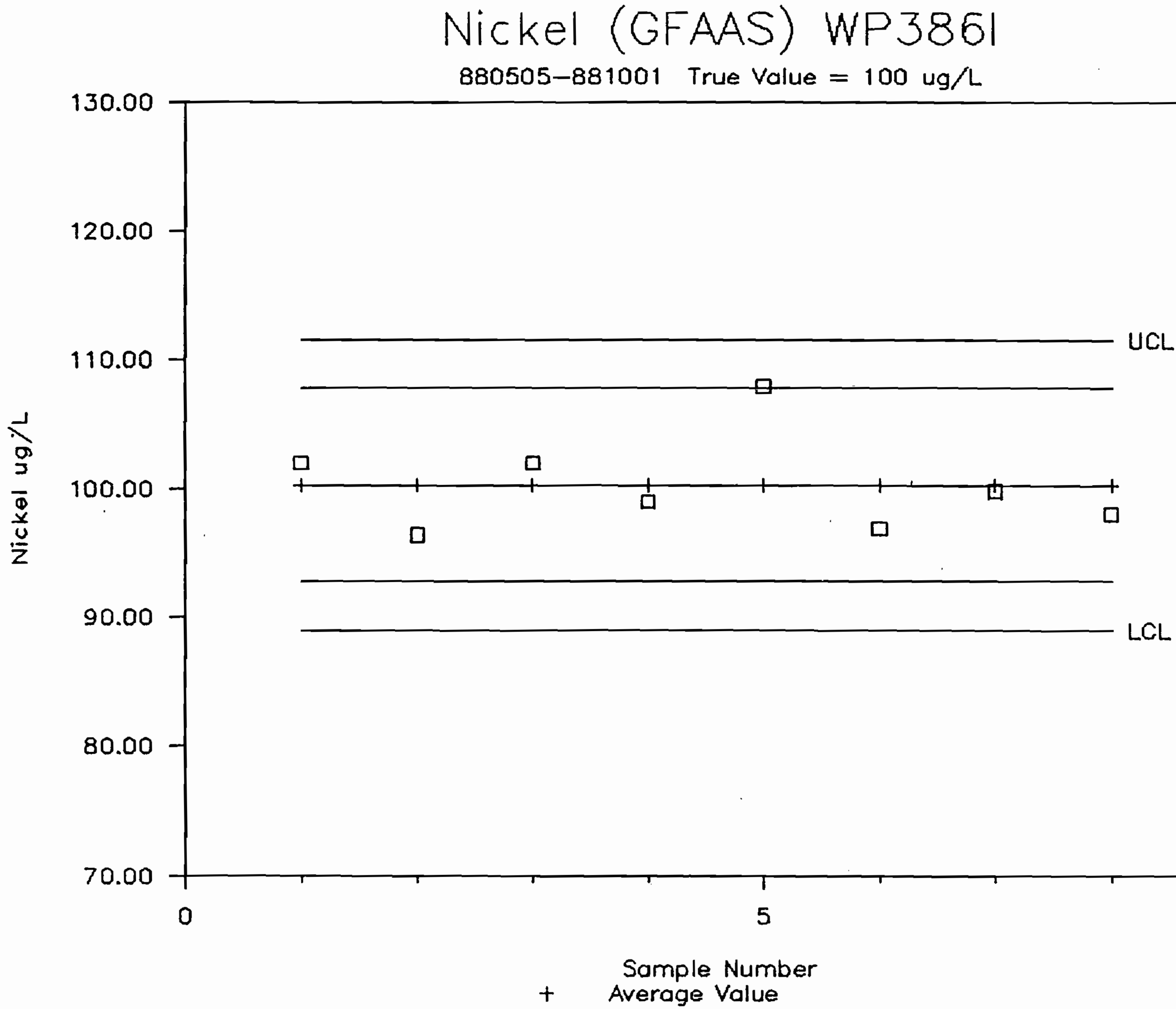

Zinc mg/L
QA+QB True Value = 10.0 mg/L
UCL
LCL
Zinc mg/L
Sample Number
+ Average Value

Selected Examples of Control Charts for Standard Reference Materials for Kiggavik Analyses

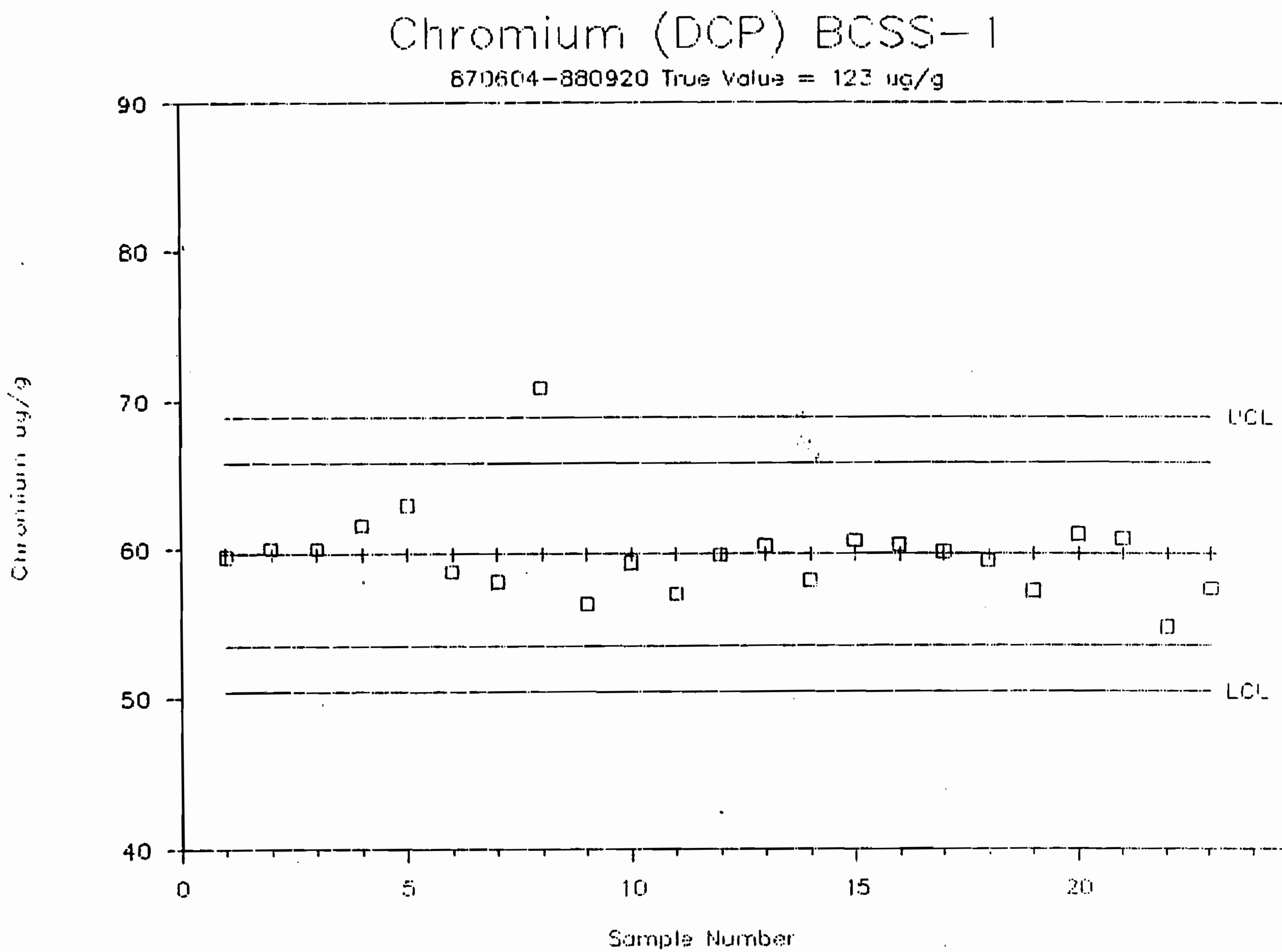


Zinc (DCP) WP386I
880609–880815 True Value = 0.1 mg/L
0.180
0.170
0.160
0.150
0.140
0.130
0.120
0.110
0.100
0.090
0.080
0.070
0.060
0.050
Zinc mg/L
UCL
LCL
0
5
10
15
20
25
30
Sample Number
\+ Average Value

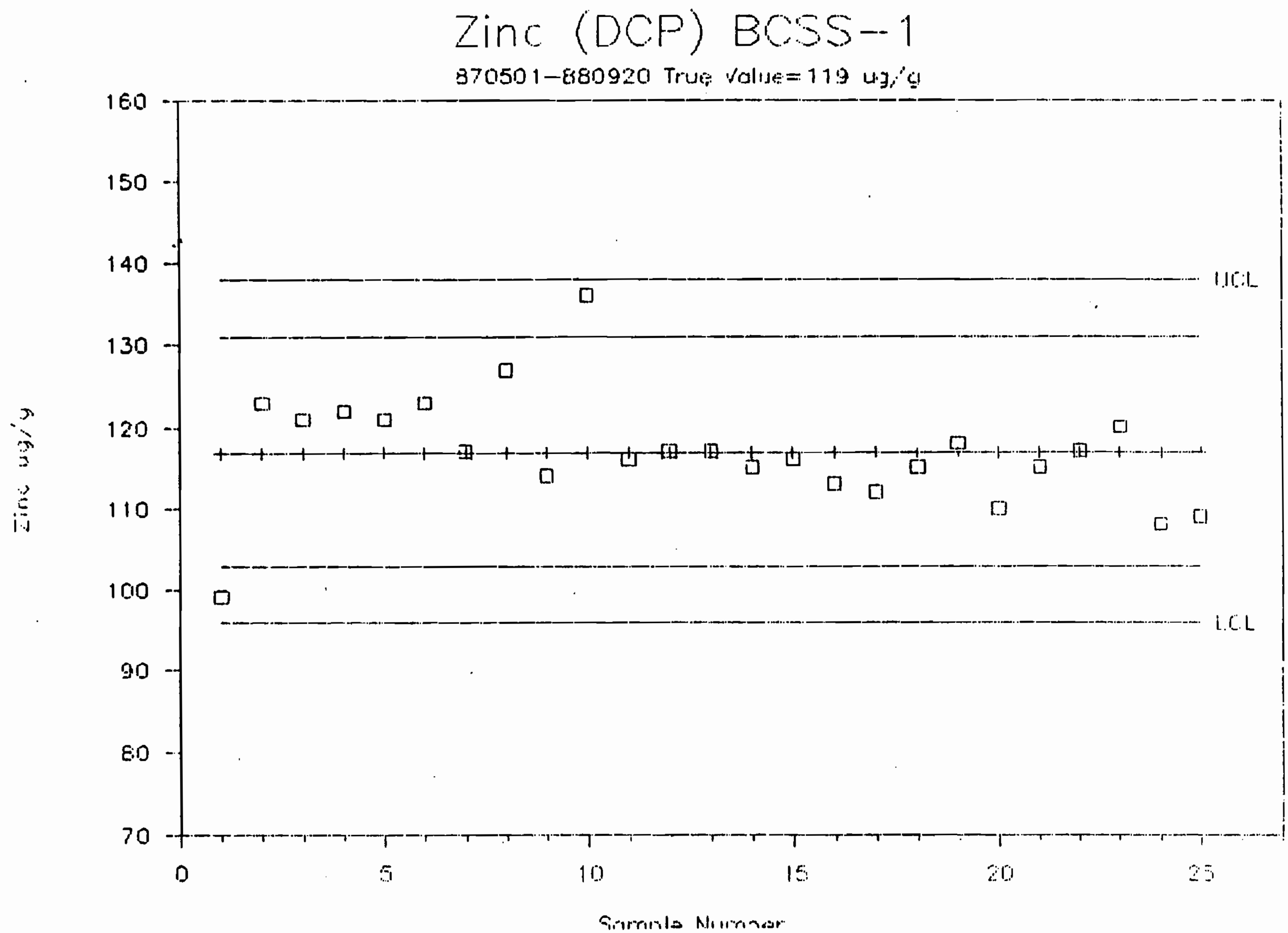

Copper (DCP) BCSS-1
870604–880920 True Value=18.5 ug/g
25
24
23
22
21
20
19
18
17
16
15
14
13
12
11
10
UCL
LCL
Copper ug/g
0
5
10
15
20
Sample Number



Nickel (GFAAS) WP386I
880505–881001 True Value = 100 ug/L
130.00
120.00
110.00
100.00
90.00
80.00
70.00
Nickel ug/L
UCL
LCL
0
5
Sample Number
+ Average Value



Chromium (DCP) BCSS-1
870604-880920 True Value = 123 ug/g
Chromium ug/g
90
80
70
60
50
40
0
5
10
15
20
Sample Number
UCL
LCL



Zinc (DCP) BCSS-1
870501-880920 True Value=119 ug/g
160
150
140
130
120
110
100
90
80
70
UCL
LCL
Zinc ug/g
0
5
10
15
20
25
Sample Number

Selected Examples of Control Charts of Differences-Between-Replicates and Replicate Data for Kiggavik Analyses

Cadmium (GFAA)

Working Range = 0.0001 - 0.005 mg/L

0 - 20%
0 - 0.001 mg/L

Replicates		R	D2
0.0003	0.0002	0.0001	0.000000
0.0004	0.0004	0	0
0.0003	0.0003	0	0
0.0002	0.0002	0	0
0.0002	0.0003	0.0001	0.000000
0.0004	0.0006	0.0002	0.000000
0.0005	0.0006	0.0001	0.000000
0.0002	0.0003	0.0001	0.000000
0.0003	0.0004	0.0001	0.000000
0.0006	0.0006	0	0
0.0004	0.0005	0.0001	0.000000
0.0002	0.0002	0	0
0.0003	0.0002	0.0001	0.000000
0.0005	0.0006	0.0001	0.000000
0.0004	0.0004	0	0
0.0004	0.0005	0.0001	0.000000
0.0002	0.0003	0.0001	0.000000
0.0004	0.0004	0	0
	Sum	0.0012	0.000000

Mean R 0.000066
S 0.000062
CL 0.000217
SW 0.000044

Precision 17.00753

20 - 50%
0.001 - 0.0025 mg/L

Replicates		R	D2
0.0011	0.001	0.0001	0.000000
0.0009	0.0011	0.0002	0.000000
0.0011	0.0011	0	0
	Sum	0.0003	0.000000

Mean R 0.0001
S 0.000091
CL 0.000326
SW 0.000064

Precision 8.694008

50 - 100%
>0.0025 mg/L

Replicates		R	D2
0.0025	0.0026	0.0001	0.000000
0.0066	0.0072	0.0006	0.000000
0.0074	0.0076	0.0002	0.000000
0.0045	0.0046	0.0001	0.000000
0.007	0.0076	0.0006	0.000000
0.0027	0.0027	0	0
0.0028	0.0028	0	0
0.004	0.0041	0.0001	0.000000
0.0098	0.0095	0.0003	0.000000
	Sum	0.002	0.000000

Mean R 0.000222
S 0.000221
CL 0.000726
SW 0.000156

Precision 4.145780

Aluminum (GFAAS)
Working Range = >5.0 ug/L

<20 ug/L

Replicates		R	D2
10	10	0	0
5	10	5	25
15	15	0	0
5	10	5	25
10	10	0	0
20	20	0	0
15	15	0	0
20	20	0	0
	Sum	10	50

Mean R 1.25
S 1.767766
CL 4.08375
SW 1.25

Precision 13.46870

20.0 - 40.0 ug/L

Replicates		R	D2
40	40	0	0
30	35	5	25
40	35	5	25
35	35	0	0
20	25	5	25
25	25	0	0
20	25	5	25
30	35	5	25
30	25	5	25
	Sum	30	150

Mean R 3.333333
S 2.886751
CL 10.89
SW 2.041241

Precision 9.447549

>40 ug/L

Replicates		R	D2
45	45	0	0
50	55	5	25
45	55	10	100
50	50	0	0
135	140	5	25
	Sum	20	150

Mean R 4
S 3.872983
CL 13.068
SW 2.738612

Precision 5.780572

Sodium (DCP)
Working Range = 0.5 - 100 mg/L

0.5 - 20 mg/L

Replicates		R	D²
2.3	2	0.3	0.09
3.5	4	0.5	0.25
6.5	7.5	1	1
5.5	5.5	0	0
2.5	4	1.5	2.25
8.5	9	0.5	0.25
9.5	9	0.5	0.25
10	10	0	0
13	13	0	0
7	6.5	0.5	0.25
3.5	3.5	0	0
2.5	2.58	0.08	0.0064
2	1.5	0.5	0.25
3.5	3.5	0	0
20	19	1	1
9	8.5	0.5	0.25
12.5	13.5	1	1
14	14	0	0
9.94	10	0.06	0.0036
9.5	9.38	0.12	0.0144
	Sum	8.06	6.8644

Mean R 0.403
S 0.414258
CL 1.316601
SW 0.292924

20 - 50 mg/L

Replicates		R	D²
24	23	1	1
21	20	1	1
40.4	40.7		
36.8	38.3		
35	34.5		
21.3	22.8		
26.1	26		
30.6	29.4		
37	37.1		
20.8	20.6		
	Sum	2	2

Mean R 1
S 0.707106
CL 3.267
SW 0.5

50 - 100%
50 - 100 mg/L

Replicates		R	D²
82	85	3	9
55	57	2	4
62	60	2	4
73	70	3	9
73	71	2	4
	Sum	12	30

Mean R 2.4
S 1.732050
CL 7.8408
SW 1.224744

Zinc (DCP) Water
Working Range = 0.01 - 10 mg/L

<0.05 mg/L

Replicates		R	D²
0.04	0.037	0.003	0.000009
0.023	0.024	0.005	0.000025
0.04	0.043	0.003	0.000009
0.012	0.013	0.001	0.000001
0.02	0.02	0	0
0.013	0.011	0.002	0.000004
0.028	0.034	0.006	0.000036
0.035	0.03	0.005	0.000025
	Sum	0.025	0.000109

Mean R 0.003125
S 0.002610
CL 0.010209
SW 0.001845

Precision 9.872630

>0.05 - <1.0 mg/L

Replicates		R	D²
0.079	0.073	0.006	0.000036
0.223	0.225	0.002	0.000004
0.48	0.5	0.02	0.0004
0.505	0.515	0.01	0.0001
0.16	0.145	0.015	0.000225
0.132	0.13	0.002	0.000004
0.05	0.054	0.004	0.000016
0.072	0.07	0.002	0.000004
0.84	0.79	0.05	0.0025
	Sum	0.111	0.003289

Mean R 0.012333
S 0.013517
CL 0.040293
SW 0.009558

Precision 6.336935

>1.0 mg/L

Replicates		R	D²
7.52	7.21	0.31	0.0961
1.35	1.395	0.045	0.002025
3.2	3.1	0.1	0.01
	Sum	0.455	0.108125

Mean R 0.151666
S 0.134241
CL 0.495495
SW 0.094923

Precision 3.387603