Aquatic Habitat Evaluation of Flooded North Slope Gravel Mine Sites (1986-1987)

by

Carl R. Hemming

Technical Report No. 88-1

Frank Rue
Director
Habitat Division
Alaska Department of Fish and Game
P.O. Box 3-2000
Juneau, Alaska 99802

August 1988

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

ACKNOWLEDGEMENTS

Several people made significant contributions to the field data collection and analysis for this report. Alaska Department of Fish and Game (ADF&G) Region III Habitat Division staff members Roger Post, Dick Shideler, Dr. Phyllis Weber, and Alan Townsend helped with field data collection. Elaine Snyder-Conn of the U. S. Fish and Wildlife Service (USFWS) and Ken Alt of the ADF&G Sport Fish Division also provided very capable field assistance. Elaine Snyder-Conn helped coordinate the loan of sampling equipment, provided technical assistance, and analyzed the water samples collected in August of 1986. Dr. Phyllis Weber identified invertebrate organisms from the collected fish stomachs and analyzed the chlorophyll-a samples. Joyce Beelman of the Alaska Department of Environmental Conservation (ADEC) identified organisms collected in the plankton tows and provided analysis of the data. Brad Fristoe and staff with ADEC North Slope District Office provided equipment support and gathered water samples for the project. Chris Garlasco and Kevin Meyers of ARCO Alaska, Inc. coordinated winter water quality sampling conducted at Sag Site C. Dr. Alvin Ott provided overall direction and significant support in the allocation of staff resources to this project.

1.0 INTRODUCTION

The Alaska North Slope was opened to petroleum development after the 1969 discovery of oil. With this development came a substantial demand for construction gravel. Early construction gravel supplies were provided by shallow scraping of river floodplain deposits. This practice was replaced by the establishment of large multi-user gravel mine sites. As the oilfields matured, some of the older gravel mine sites became depleted whereas newer sites are still operational. Both the depleted and operational sites are large, deep features with surface areas ranging from 1.5 ha (3.7 ac) to 47.5 ha (117.3 ac) and with the bases of most sites from 12 to 15 m below the ground surface elevation. When these sites are no longer required to supply current or anticipated gravel needs, some are converted to surface water reservoirs.

The conversion procedure involves diverting an adjacent stream or river into the mine site excavation through a breach in the pit perimeter berm. This process uses spring flood water and can take from 3 days (Sag Site C) to 3 yr (Kuparuk Mine Site D) depending on the size of the mine site and the discharge of the adjacent stream or river being diverted. Once full, the resultant newly created lake provides a readily accessible water source for various industrial and domestic uses.

Unlike the numerous, naturally occurring shallow tundra ponds and lakes, flooded gravel mine sites are deep basins which represent a unique aquatic habitat type in the Mid-Beaufort Region (Colville to Canning River). Typical lentic habitats in the region are formed by localized depressions in the tundra. These ponds and lakes are created by melting of the ground surface following a local disturbance or melting of ice wedges, are generally shallow (less than 2 m), and often freeze solid by late winter. Due to such physical characteristics, fish usage of tundra ponds is limited. Flooded gravel mine sites differ from local lakes because they are deep enough to maintain significant quantities of under-ice water. The flooded mine sites are morphologically similar to deep lake basins formed by glacial processes such as those found in the Foothill Region north of the Brooks Range. Deep lakes are important as aquatic habitat because they hold sufficient under-ice water to support overwintering fish.

1.1 Project Background

The Alaska Department of Fish and Game (ADF&G) has been actively involved in resource management policy regarding gravel and water use within the North Slope oilfields since the mid-1970's. State management policies such as the prohibition of water removal from streams during the winter season and the establishment of large multi-user gravel extraction sites were formulated with the ADF&G's biological input on the impacts of water and gravel use on local fish and wildlife. In 1975, the U.S. Fish and Wildlife Service (USFWS) funded a 5-yr study on the effects of gravel removal from floodplain habitats in arctic and subarctic environments (Joyce et al. 1980). Based in part on the results of the USFWS studies, the ADF&G Habitat Division initiated aquatic habitat and fisheries investigations at three selected flooded gravel mine sites in the summer of 1986. The initial focus of the study was to document fish usage of the selected sites. Data were also gathered on selected physical and chemical characteristics considered important for evaluating the sites as aquatic habitat. In 1987, the data collection program was expanded to include the Kuparuk Deadarm area, and chlorophyll-a analysis and zooplankton sampling elements were added to the study.

1.2 General Objectives

The primary objective of this study is to maximize the benefits to fish and wildlife from the management of flooded gravel mine site habitat. The intent of collecting data on the physical, chemical, and biological features of selected gravel mine sites is to identify those features that make the sites most suitable for use by fish and wildlife. The preliminary information has already been used to make specific recommendations on rehabilitation measures for such sites with the goal of increasing biological productivity and fish use. In addition to the rehabilitation of existing sites, new gravel mine sites can be designed to incorporate those features that maximize biological productivity and use by local fish and wildlife populations, based on the results of continuing studies.

This technical report is intended to provide the background information for continuing ADF&G studies of flooded mine sites on Alaska's North Slope. The report also presents the results of the initial 2 yr of the project. As project scope, emphasis, and data collection continue to evolve, we will prepare annual progress reports that build upon the baseline information presented herein.

2.0 SITE INVENTORY AND SELECTION

Gravel mine sites in the Prudhoe Bay, Kuparuk, and Endicott oilfields, as shown in Figure 1, were inventoried from aerial photographs (scale: 1 in = 1,500 ft). Estimates of surface area were generated from the aerial photography with computer-assisted electronic digitizing equipment. The inventory included flooded gravel mine sites and operational mine sites that may be flooded at some time in the future. A total of 19 basins were identified. The cumulative surface area of these excavations is approximately 324 ha (800 ac). Individual sites range from 1.5 ha (3.7 ac) to 47.5 ha (117.3 ac) with an average size of 17 ha (42 ac). Of the 19 sites identified, 11 have been flooded with water. The 11 flooded sites account for approximately 98 ha (247 ac) of lake habitat. Information on the size, depth, and stream source of the 11 flooded sites is presented in Table 1. Eight deep gravel mine sites covering an area of 225.9 ha (558.2 ac) may be flooded at some time in the future. Information on these sites is presented in Table 2.

ARCO Sag Site C and Kuparuk Mine Sites B and D were initially selected for investigation. Sag Site C is a 15.5-ha (38.2-ac) site located in the floodplain of the West Channel of the Sagavanirktok (Sag) River. The site is bounded on the south side by the Sag River causeway and to the north by the Sag River oil pipeline crossing. The pit was flooded on June 8, 1986 when the perimeter berm on the west side of the site was breached allowing Sag River flood water to enter the pit. The site filled with an estimated 2.46×10^9 L (6.50×10^8 gal) of water within a 72-hr period. During breakup in 1987, an outlet channel developed on the northeast corner of the pit, and continuous surface flow existed throughout the remainder of the summer between the pit and a major channel of the Sag River. Sag Site C was selected for study because of the need for information to aid in the development of a restoration plan. The site was also considered a high priority because it is seasonally connected to the Sag River. The Sag River system supports the greatest fish abundance and species diversity of the stream and river systems draining the oilfield area.

Kuparuk Mine Site D was also selected because of the need for information to support ongoing rehabilitation planning. It is the largest flooded mine site connected to a tundra stream system, covering 15.6 ha (38.7 ac) adjacent to "Charlie Creek," a western tributary to the Ugnuravik River system. The Ugnuravik River is a tundra system reported to contain ninespine stickleback as the only species of fish present (Moulton 1980, Dew 1981). Tundra drainages such as the Ugnuravik that are not tributary to larger river

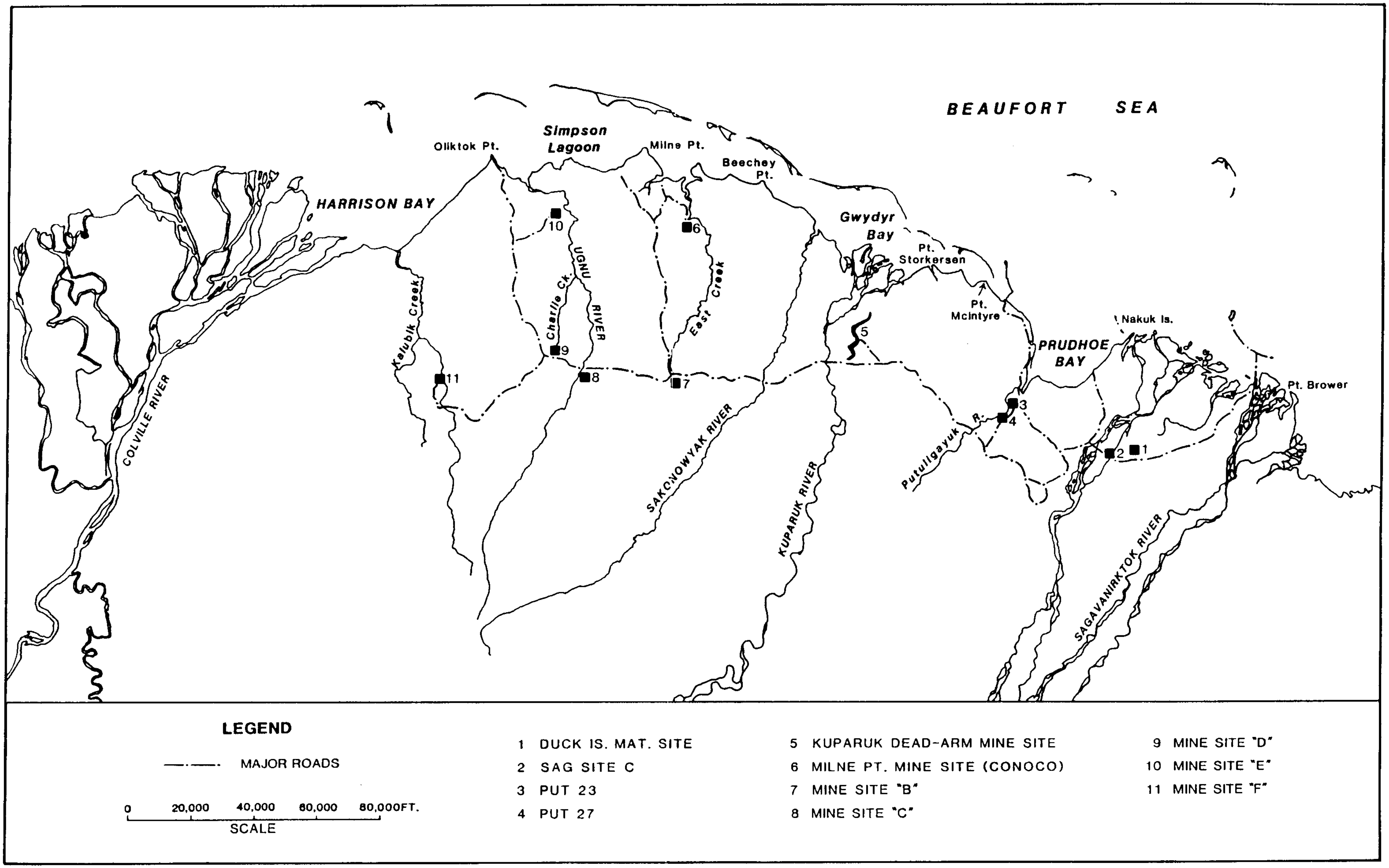

BEAUFORT SEA
HARRISON BAY
Oliktok Pt.
Simpson Lagoon
Milne Pt.
Beechey Pt.
Gwydyr Bay
Pt. Storkersen
Pt. McIntyre
Nakuk Is.
PRUDHOE BAY
Pt. Brower
COLVILLE RIVER
Kalubik Creek
Charlie Ck.
UGNU RIVER
East Creek
SAKONOWYAK RIVER
KUPARUK RIVER
Putuligayuk R.
SAGAVANIRKTOK RIVER
LEGEND
MAJOR ROADS
0 20,000 40,000 60,000 80,000FT.
SCALE
1 DUCK IS. MAT. SITE
2 SAG SITE C
3 PUT 23
4 PUT 27
5 KUPARUK DEAD-ARM MINE SITE
6 MILNE PT. MINE SITE (CONOCO)
7 MINE SITE "B"
8 MINE SITE "C"
9 MINE SITE "D"
10 MINE SITE "E"
11 MINE SITE "F"

TABLE 1. Inventory of 11 flooded gravel mine sites in the Mid-Beaufort Region, Alaska

Site	Stream Source		Surface Area (ha[ac])	Maximum Depth (m[ft])	Average Depth (m[ft])
Kuparuk Deadarm	Kuparuk River, East Channel				
1	"		1.5[3.7]	n/a[1]	n/a
2	"		2.8[6.9]	n/a	n/a
3	"		3.6[8.8]	n/a	n/a
4	"		7.7[19.0]	14.3[47]	9.1[30.0]
5	"		27.5[67.9]	17.4[57]	11.4[37.5]
6	"		15.2[37.6]	7.6[25]	2.5[8.3]
		Total	58.3[143.6]		
Kuparuk B Pit	East Creek				
Area A	"		1.3[3.3]	11.3[37]	7.3[23.8]
Area B	"		2.3[5.8]	9.8[32]	6.9[22.5]
		Total	3.7[9.1]		
Kuparuk D Pit	Charlie Creek, trib to Ugnuravik River		15.6[38.7]	18.3[60]	14.0[45.8]
Sag Site C	Sagavanirktok River, West Channel		15.5[38.2]	23.5[77]	16.8[55.1]
Kuparuk C Pit (flooded portion)	Ugnuravik River		4.5[11.0]	n/a	n/a
Total area for all flooded mine sites = 97.5 ha [246.6 ac]					

1. n/a = data not available.

TABLE 2. Inventory of eight deep gravel mine sites that may be converted to lakes upon abandonment, Mid-Beaufort Region, Alaska.

Site	Potential Stream Source	Surface Area (ha[ac])	Approximate Distance to Stream (m[ft])	Comments
Endicott	Sagavanirktok R. side channel	35.8[88.5]	300 [1000]	flooded wetlands adjacent to pit
Put River #23				
- Northern Section	Putuligayuk R.	42[104]	60 [200]	source water potentially brackish, site in close proximity to estuarine area
- Southern Section		38.1[94.2]		
Put River #27	Putuligayuk R.	15.9[39.4]	120 [400]	" "
Milne Point (Conoco) Pit	unnamed tundra stream	4.0[9.9]	120 [400]	source water potentially brackish, site in close proximity to the coast
Kuparuk E Pit (Ugnu)	Ugnuravik River	30.7[75.9]	300 [1000]	water accumulating in pit reported to be brackish
Kuparuk F Pit	Kalubik Creek	11.9[29.4]	120 [400]	expansion of pit proposed
Kuparuk C Pit	Ugnuravik River	47.5[117.3]	60 [200]	northern portion of pit flooded and serves as water reservoir for Central Production Facility (CPF) #1

Total area for unflooded mine sites = 225.9 ha (558.6 ac) systems, and drain directly to the Beaufort Sea, are generally considered limited in fish abundance and species diversity due to the lack of suitable overwintering habitat.

Mine Site D was flooded following the excavation of a diversion channel between the site and Charlie Creek during the first week of June 1984. The diversion project resulted in significant erosion in the diversion channel and in Charlie Creek. As a result of the diversion, the stream's entire flow adjacent to the mine site entered the pit during 1984 and 1985. In 1986, the mine site water level reached the stream water surface elevation, the erosional process abated, and stream flow downstream of the pit was re-established. The erosional feature is up to 30 m wide and 12 m deep for 60 m between the mine site and the stream and becomes narrower and shallower as it extends upstream in Charlie Creek to a point roughly 200 m above the diversion channel's intersection with the creek.

Kuparuk Mine Site B is an older, smaller site than the others investigated. The excavated area was flooded in 1978 and is connected to a tundra stream known locally as "East Creek." East Creek drains directly to the Beaufort Sea. As in the Ugnuravik River system, the ninespine stickleback is the only species of fish documented to be present in this drainage (Dew 1981). The lake covers 3.7 ha (9.1 ac) consisting of two adjacent basins each connected independently to East Creek. The site was selected for investigation in part because of its atypical size and shape.

In 1987, Standard Alaska Production Company's (SAPC) Kuparuk Deadarm Gravel Extraction Area was added to the study program. Communication between SAPC and the state regarding closing portions of the site and potentially developing a rehabilitation plan led to the site's addition to the study program. The Kuparuk Deadarm area is a former high-water channel on the east side of the Kuparuk River floodplain. The site consists of six connected flooded gravel mine sites covering 58.3 ha (143.6 ac). The lower sites were flooded by water backing up into the high-water channel from the East Channel of the Kuparuk River in 1986. The Kuparuk River is a large river system known to support several species of freshwater and anadromous fish. The presence of fish overwintering habitat has been documented in the lower Kuparuk River (Bendock 1977).

3.0 BIOLOGICAL SAMPLING

3.1 Methods

Experimental gill nets were fished at selected locations in each of the mine sites investigated. The nets were 38.1 m long consisting of five 7.6-m panels having mesh sizes of 1.3, 2.5, 3.8, 5.1, and 6.4 cm. Both sinking and floating nets were used at each site. During summer, the nets were anchored from shore and set with an inflatable boat powered by an outboard motor. Winter sampling, with the above-described sinking gill nets, was done under the ice using the "Murphy Stick" method as described by Bendock (1980). Wire minnow traps baited with salmon eggs were fished at selected sites. All sampling gear was deployed at structural features determined likely to attract fish.

The catch at each location was identified and enumerated. Those fish that did not appear severely injured were released. Additional data consisting of length, sexual condition, and stomach fullness were obtained from the retained portion of the catch. Those stomachs containing food items were removed and preserved in alcohol for analysis. Stomach samples were separated by fish species and by collection site. Individual organisms were identified and enumerated or a grid sample was used to generate an estimate of the total number of organisms when they were too numerous to count. Individual organisms in the stomach contents were identified to the most specific taxonomic level practical with a dissecting microscope. Where possible, identification of food items was completed on preserved samples to characterize the types of food taken by each species of fish captured at each site.

Plankton tows were conducted at each of the sites investigated. A vertical-tow net was used to collect zooplankton in the water column. Because of the low density of organisms collected in the vertical tows the procedure was modified, and the net was towed horizontally behind the raft to increase the volume of water filtered. Zooplankton organisms were collected from each pit and stored in plastic collection bottles. The sampling methods provided qualitative information on the zooplankton communities at each of the sites.

Chlorophyll-a sampling was conducted on August 13-15, 1987 to determine the standing crop of phytoplanktonic organisms. Water samples of 1.0 L were gathered from arbitrarily selected locations considered typical of the habitats occurring at each mine site. The 1.0 L samples were filtered to separate chlorophyll-containing organisms from the water sample. The filters were treated with magnesium carbonate to prevent acidification of the chlorophyll, then frozen pending analysis. The samples were treated by grinding in 90% acetone, then allowed to extract for two hours. Samples were then centrifuged and absorbance of the supernatant was determined on a spectrophotometer, according to Standard Methods (Sixteenth Edition). Amounts of chlorophyll-a were determined using a tri-chromatic method and corrected for turbidity. The samples were not acidified to correct for phaeophytin; therefore, the chlorophyll-a data represent both living and dead algal cells.

3.2 Results

The overall biological characteristics of the flooded gravel mine sites investigated in this study are presented in Table 3. Arctic grayling were found in those sites connected to large river systems (e.g., Sagavanirktok and Kuparuk rivers) but were not found in the sites connected to tundra stream systems. Conversely, ninespine sticklebacks were found in abundance in the sites connected to tundra streams but were not found in the sites connected to large river systems. Arctic char and round whitefish were found in Sag Site C, broad whitefish were found in Sag Site C and Kuparuk Mine Site B, arctic cisco were found in the Kuparuk Deadarm, and a single least cisco was found in Kuparuk Mine Site D.

The greatest abundance and species richness of zooplankton were found in the Kuparuk Deadarm and Kuparuk Mine Site B. Kuparuk Mine Site B had the highest surface chlorophyll-a concentration of the sites investigated in this study. Surface chlorophyll-a concentrations were lower at the other sites but were comparable to each other.

More detailed results are presented for each site in the following sections of this report.

3.2.1 Sag Site C - Fish sampling was conducted at Sag Site C three times during 1986 and 1987. The first sampling period was August 19-21, 1986; late winter under-ice sampling occurred on April 28 and 29, 1987; and the third sampling period occurred on July 13 and 14, 1987. The site was flooded on June 6-8, 1986; therefore, the fish sampling data represent colonization of the site during the first two open-water seasons. The fish sampling locations are shown in Figure 2. The catch results for each location are presented in Table 4. Fish were captured during both open-water sampling periods. The winter sampling effort, consisting of one experimental gill net set under the ice for 15.5 hr, failed to capture fish. The

TABLE 3. Summary of biological characteristics of selected gravel mine sites in the Mid-Beaufort Region, Alaska

Mine Site	Fish Species Captured	Fish Species Abundance*	Zooplankton Genera Collected	Zooplankton Abundance**	Chlorophyll-a Surface Concentration (ug/L)
Sag C	arctic grayling arctic char round whitefish broad whitefish	high low low low	Diaptomus	low	1.70
Kuparuk B	ninespine stickleback broad whitefish	high moderate	Diaptomus Hetercope	moderate	7.37 (area A) 3.83 (area B) 5.32 (area B)
Kuparuk D	ninespine stickleback least cisco	high low	Diaptomus	low	0.88 1.57 1.70 2.21 (Charlie Creek)
Kuparuk Deadarm Reservoirs 4 and 5	arctic grayling arctic cisco	moderate moderate	Diaptomus Heterocope Cyclops Daphnia	moderate	1.07 0.86 2.23
Kuparuk Deadarm Reservoir 6	arctic grayling arctic cisco	low moderate	Diaptomus Heterocope Cyclops Daphnia	high	1.20 1.11 1.22

* Fish abundance rating: 1-4 fish captured = low, 5-10 captured = moderate, over 10 captured = high. The ratings provide a basis for comparison between the sites investigated but do not account for differences in gear type, effort, or size of the site.
** Zooplankton abundance is based on a subjective evaluation of the relative density of organisms found in the sample sites investigated.

FIGURE 2

SAG SITE C
Fish Sampling Locations

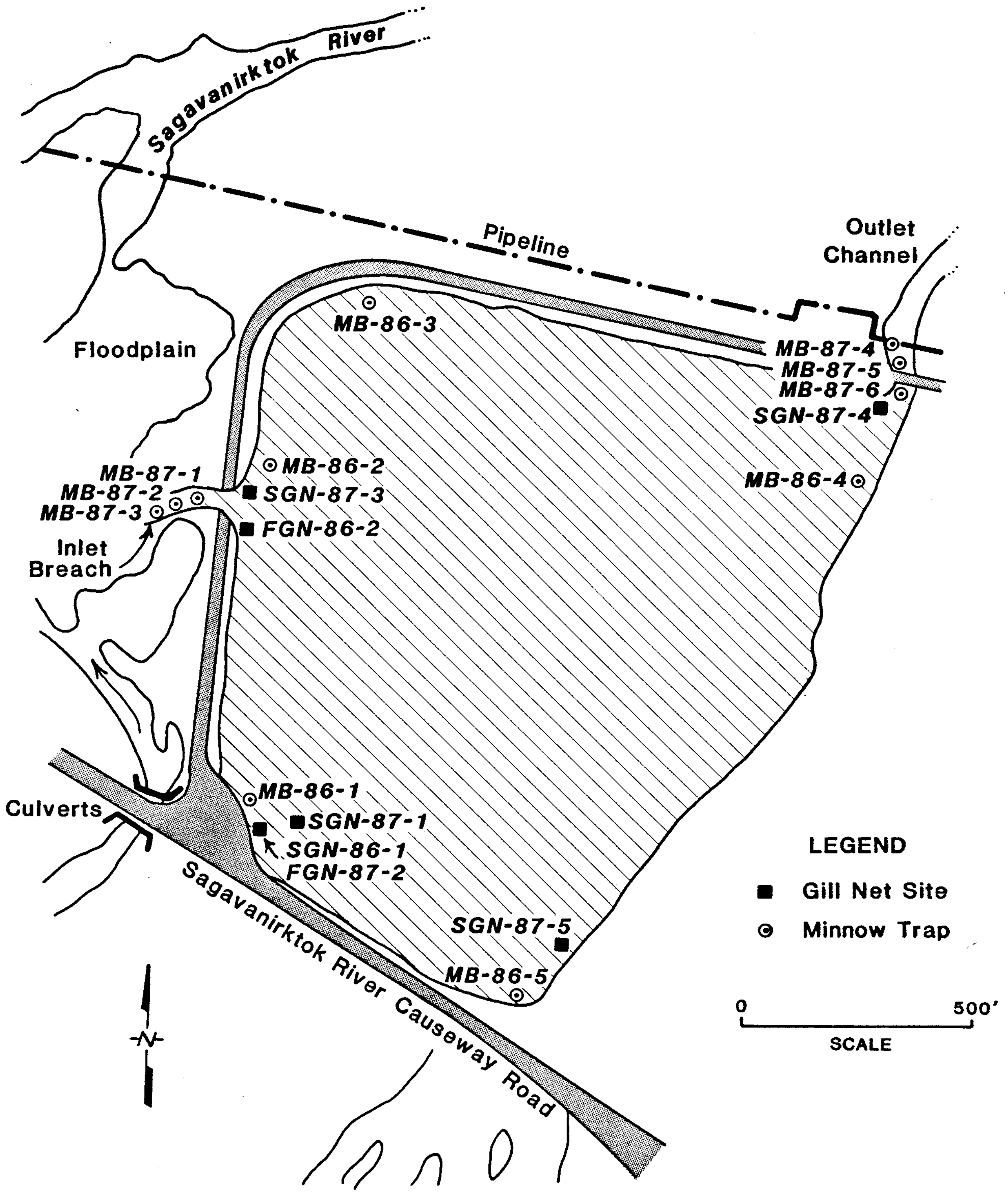


TABLE 4. Summary of fish sampling gear, effort, and catch in 1986 and 1987 at Sag Site C, Mid-Beaufort Region, Alaska.

Location Code	Dates	Gear Type	Elapsed Time (hr)	Catch	CPUE (fish/hr)
SGN-86-1	Aug. 19-21	125' variable mesh sinking gill net	48	23 arctic grayling 1 arctic char	0.48
FGN-86-2	"	125' variable mesh floating gill net	"	1 arctic grayling	0.02
MB-86-1	"	minnow trap	"	0	0
MB-86-2	"	"	"	0	0
MB-86-3	"	"	"	0	0
MB-86-4	"	"	"	1 arctic char	0.02
MB-86-5	"	"	"	0	0
SGN-87-1	April 27-28	125' variable mesh sinking gill net	15.5	0	0
FGN-87-2	July 13-14	125' variable mesh floating gill net	18	6 arctic grayling 1 broad whitefish	0.38
SGN-87-3	"	125' variable mesh sinking gill net	"	9 arctic grayling 2 broad whitefish 1 round whitefish 1 arctic char	0.72
SGN-87-4	"	"	"	6 arctic grayling	0.33
SGN-87-5	"	"	"	7 arctic grayling 1 round whitefish	0.44

Table 4. continued

Location Code	Dates	Gear Type	Elapsed Time (hr)	Catch	CPUE (fish/hr)
MB-87-1	July 13-14	minnow trap	18	0	0
MB-87-2	"	"	"	0	0
MB-87-3	"	"	"	0	0
MB-87-4	"	"	"	0	0
MB-87-5	"	"	"	0	0
MB-87-6	"	"	"	0	0

1986 catch for both minnow traps and gill nets consisted of 24 arctic grayling and 2 arctic char. The 1987 catch for both types of gear consisted of 28 arctic grayling, 3 broad whitefish, 2 round whitefish and 1 arctic char. The species composition for the 1986 and 1987 test net and minnow trap catch is presented in Figure 3.

Nineteen of the 24 arctic grayling and both of the arctic char captured in 1986 were retained for analysis. The age, length, and sexual condition of the 1986 catch are presented in Appendix A. The arctic grayling captured ranged from 214 mm to 284 mm (fork length) and averaged 256 mm. The sample catch consisted primarily of age class five and six fish. The size and age distribution of the sample catch is presented in Appendix B.

A qualitative analysis of the stomach contents of arctic grayling captured from Sag Site C in 1986 was conducted with emphasis on identification of the types of food items taken. All of the arctic grayling captured had been actively feeding as evidenced by full or partially full stomachs. Identifiable food items occurring most frequently were terrestrial insects and copepods. The organisms identified are presented in Appendix C.

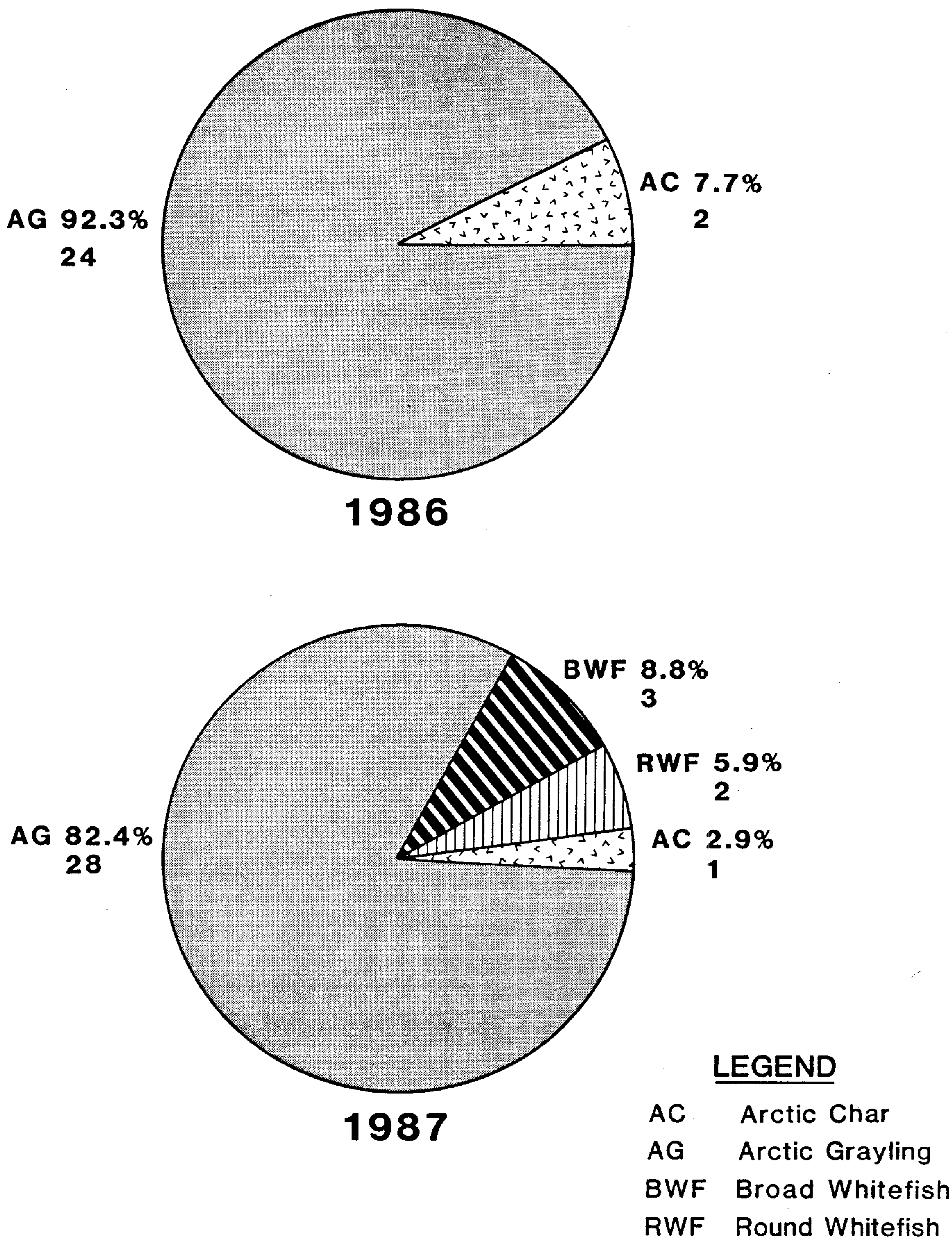
The two arctic char captured in Sag Site C in 1986 had empty stomachs. The larger (490 mm) fish appeared to be in poor condition, with a small body size (girth) in relation to its length.

During the July 1987 sampling period, round whitefish and broad whitefish were captured, in addition to arctic grayling. The former two species had not been captured during the August 1986 test net sampling period. The presence of two additional species of fish in the 1987 catch and the increased catch per unit effort at most net sites (Table 4) indicate that additional fish may have moved into the site during the 1987 open-water season.

In 1987, 18 arctic grayling, 1 broad whitefish, 2 round whitefish, and 1 arctic char were retained for analysis. The arctic grayling ranged from 225 mm to 338 mm (fork length) and averaged 271 mm in length. As in 1986, arctic grayling had been actively feeding. The length, sex, and stomach fullness of the retained portion of the 1987 test net catch are presented in Appendix D.

FIGURE 3

SAG SITE C SAMPLE CATCH
Species Composition



Stomach contents of the fish in the 1987 test net sample catch at Sag Site C were enumerated and identified. The numerical values presented in Appendix E identify those items that were taken most frequently by each species of fish captured. Diptera made up most of the arctic grayling diet, as well as that of the broad whitefish and round whitefish in the sample.

Chlorophyll-a concentrations in Sag Site C in mid-August 1987 ranged from 1.06 to 1.75 ug/L. Appendix I presents complete sampling results for chlorophyll-a.

Zooplankton samples collected from Sag Site C in 1987 consisted exclusively of Diaptomus sp., a calanoid copepod. This is consistent with the presence of copepods in the stomachs of arctic grayling collected at this site in 1986.

3.2.2 Kuparuk Mine Site B - Fish sampling was conducted at Kuparuk Mine Site B on August 19-21, 1986 and July 15-16, 1987. The sampling locations are shown in Figure 4. The catch results for each location are presented in Table 5. In 1986, two experimental gill nets and six minnow traps were fished. The catch consisted of 21 ninespine sticklebacks captured in the minnow traps. The fish sampling effort was limited to the northern lobe (Area A) of the pit in 1986. In 1987, experimental gill nets were fished in both lobes of the pit. The net in the northern lobe (Area A) failed to capture fish whereas the net in the southern lobe (Area B) captured five broad whitefish. Four of the broad whitefish were retained for analysis. The length, sex, and maturity data collected from the retained portion of the catch are presented in Appendix F.

Stomach samples were analyzed from two of the broad whitefish captured from Kuparuk Mine Site B. Identification and enumeration of fish food items found in broad whitefish stomachs are presented in Appendix F.

Dipteran larvae were the predominant food item found in broad whitefish at the site; however, the number of food items found in Kuparuk Mine Site B broad whitefish was greater than that found in broad whitefish captured in Sag Site C. Caddisfly larvae and fresh water snails were present in the stomach contents from Mine Site B broad whitefish.

FIGURE 4

KUPARUK MINE SITE B
Fish Sampling Locations

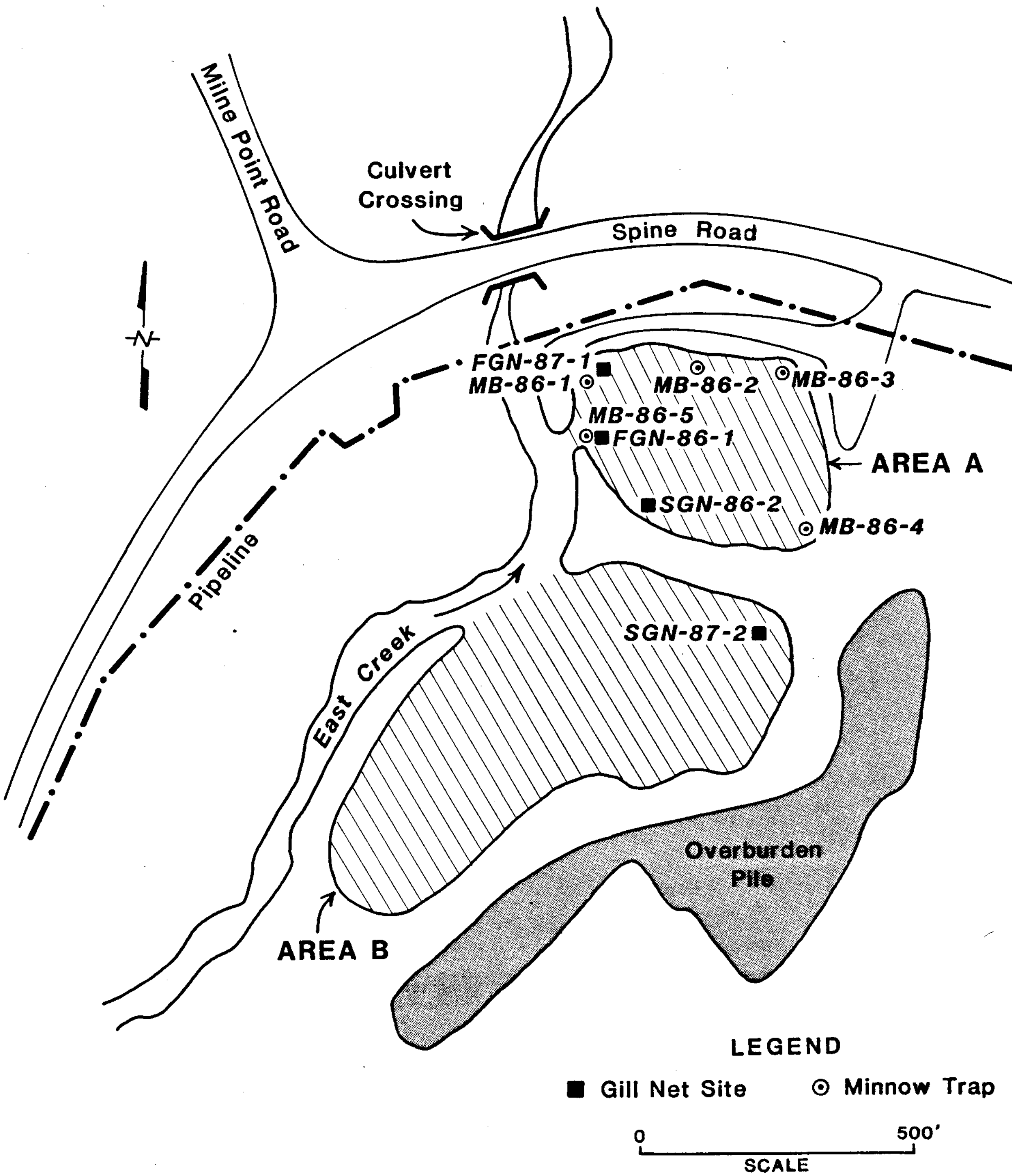


TABLE 5. Summary of fish sampling effort, gear, and catch in 1986 and 1987 at Kuparuk Mine Site B, Mid-Beaufort Region, Alaska.

Location Code	Dates	Gear Type	Elapsed Time (hr)	Catch	CPUE (fish/hr)
FGN-86-1	Aug. 19-21	125' variable mesh floating gill net	48	0	0
SGN-86-2	"	125' variable mesh sinking gill net	"	0	0
MB-86-1	"	minnow trap	"	9 ninespine stickleback	0.19
MB-86-2	"	"	"	6 "	0.12
MB-86-3	"	"	"	3 "	0.06
MB-86-4	"	"	"	1 "	0.02
MB-86-5	"	"	"	2 "	0.04
FGN-87-1	July 15, 16	125' variable mesh floating gill net	17	0	0
SGN-87-2	"	125' variable mesh sinking gill net	17	5 broad whitefish	0.29

Chlorophyll-a concentrations in Kuparuk Mine Site B in mid-August 1987 ranged from 3.05 to 7.37 ug/L. Area A, the northern portion of the pit, was characterized by higher concentrations than Area B. Appendix I presents complete sampling results for chlorophyll-a.

Zooplankton tows in Kuparuk Mine Site B yielded the calanoid copepods *Diaptomus* sp. and *Heterocope septentrionalis*. These species were not apparent in the stomach contents of broad whitefish captured at this site.

3.2.3 Kuparuk Mine Site D - Fish sampling was conducted at Kuparuk Mine Site D on August 19-21, 1986; April 30 to May 1, 1987; and July 14-15, 1987. The locations of the sample stations are identified in Figure 5. The catch results for each sample location are presented in Table 6. In August 1986, a single least cisco was captured in Kuparuk Mine Site D. The least cisco was a 6-yr old, 280-mm (fork length), mature male. Movement of this fish into Mine Site D most likely occurred in 1986 as it was the first year the mine site water level reached the same elevation as Charlie Creek. Mine Site D is located approximately 23.0 km upstream of the Ugnuravik River mouth. During the 1987 sampling period, two minnow traps set upstream of the eroded area on Charlie Creek produced large catches of ninespine stickleback. The traps captured 437 ninespine sticklebacks within an 18-hr period. The productive trap locations were shallow water areas (30 cm) characterized by emergent vegetation. The net sites located off the inlet breach and at the northeast corner of the pit had significant accumulations of organic debris from thawing peat deposits eroding from the pit walls.

Chlorophyll-a concentrations in Kuparuk Mine Site D in mid-August 1987 ranged from 0.88 to 2.21 ug/L, although the latter value was obtained in Charlie Creek adjacent to the pit. Appendix I presents complete sampling results for chlorophyll-a.

Zooplankton tows in Kuparuk Mine Site B yielded only the calanoid copepod *Diaptomus* sp.

3.2.4 Kuparuk Deadarm - Fish sampling was conducted on August 11-12, 1987 in the Kuparuk Deadarm Gravel Extraction Area. This area consists of six interconnected basins. Two nets were fished in each of the two largest basins (Reservoirs 5 and 6). The locations of the sample stations are identified in

FIGURE 5

KUPARUK MINE SITE D
Fish Sampling Locations

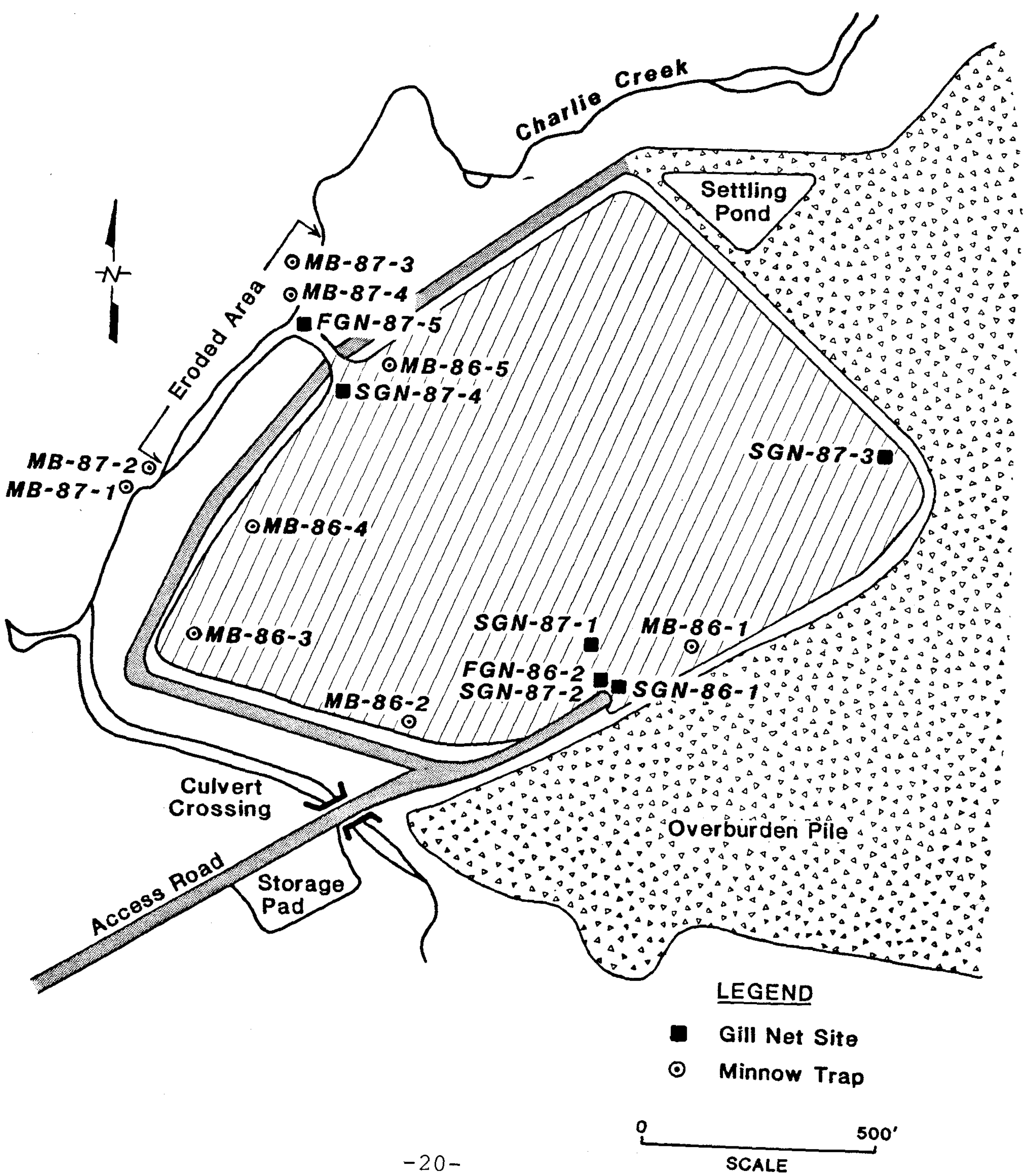


TABLE 6. Summary of fish sampling gear, effort, and catch in 1986 and 1987 at Kuparuk Mine Site D, Mid-Beaufort Region, Alaska.

Location Code	Dates	Gear Type	Elapsed Time (hr)	Catch	CPUE (fish/hr)
SGN-86-1	Aug. 19-21	125' variable mesh sinking gill net	48	0	0
FGN-86-2	"	125' variable mesh floating gill net	"	1 least cisco	0.02
MB-86-1	"	minnow trap	"	0	0
MB-86-2	"	"	"	0	0
MB-86-3	"	"	"	0	0
MB-86-4	"	"	"	0	0
MB-86-5	"	"	"	0	0
SGN-87-1	April 30-May 1	125' variable mesh sinking gill net	19.5	0	0
SGN-87-2	July 14-15	"	18	0	0
SGN-87-3	"	"	"	0	0
SGN-87-4	"	"	"	0	0
FGN-87-5	"	125' variable mesh floating gill net	"	0	0
MB-87-1	"	minnow trap	"	283 ninespine stickleback	15.72
MB-87-2	"	"	"	154 "	8.55
MB-87-3	"	"	"	1 "	0.06
MB-87-4	"	"	"	0 "	0

Figure 6, and the catch results at each sample location are presented in Table 7. The combined catch from four gill net sites was 10 arctic cisco and 8 arctic grayling (Figure 7). The catch in Reservoir 6 consisted of five arctic cisco and one arctic grayling. The nets were fished for 20 hr yielding a catch of 0.15 fish per net-hr. All fish captured in Reservoir 6 were retained for analysis. Data obtained from the catch are presented in Appendix G. Arctic cisco ranged from 368 mm to 425 mm and averaged 387 mm. Fish stomach content analysis is presented in Appendix H. The copepod Diaptomus sp. and the cladoceran Daphnia sp. made up the entire stomach contents of arctic cisco from Reservoir 6.

The net catch in Reservoir 5 consisted of five arctic cisco and seven arctic grayling. The nets were fished for 22 hr yielding 0.27 fish per net-hr. Three arctic cisco and five arctic grayling were retained for analysis. The data obtained from the catch are presented in Appendix G. Four arctic grayling were 114 mm long while the remaining grayling was 292 mm. Arctic cisco ranged from 381 mm to 393 mm in length with an average length of 385 mm.

Stomach contents from two arctic cisco and one arctic grayling were examined. The former contained Daphnia sp. and the latter contained zooplankton parts. The results of the stomach analysis are presented in Appendix H.

Chlorophyll-a concentrations at the two Kuparuk Deadarm sites ranged from 0.86 to 2.23 ug/L at Reservoir 5 and from 1.11 to 18.33 ug/L at Reservoir 6. Excluding the latter concentration, which likely reflects periphyton, Reservoir 6 had a high concentration of 1.84 ug/L. Appendix I presents complete sampling results for chlorophyll-a.

Zooplankton sampling at the two Kuparuk Deadarm sites yielded the calanoid copepods Diaptomus sp. and Heterocope septentrionalis, the copepod Cyclops sp., and the cladoceran Daphnia sp. This is consistent with the stomach contents of arctic cisco captured from the Deadarm sites; the ciscos were feeding exclusively on planktonic food items. The most abundant organisms in the Deadarm sites were Diaptomus sp. and Daphnia sp.

FIGURE 6

KUPARUK DEADARM
Fish Sampling Locations

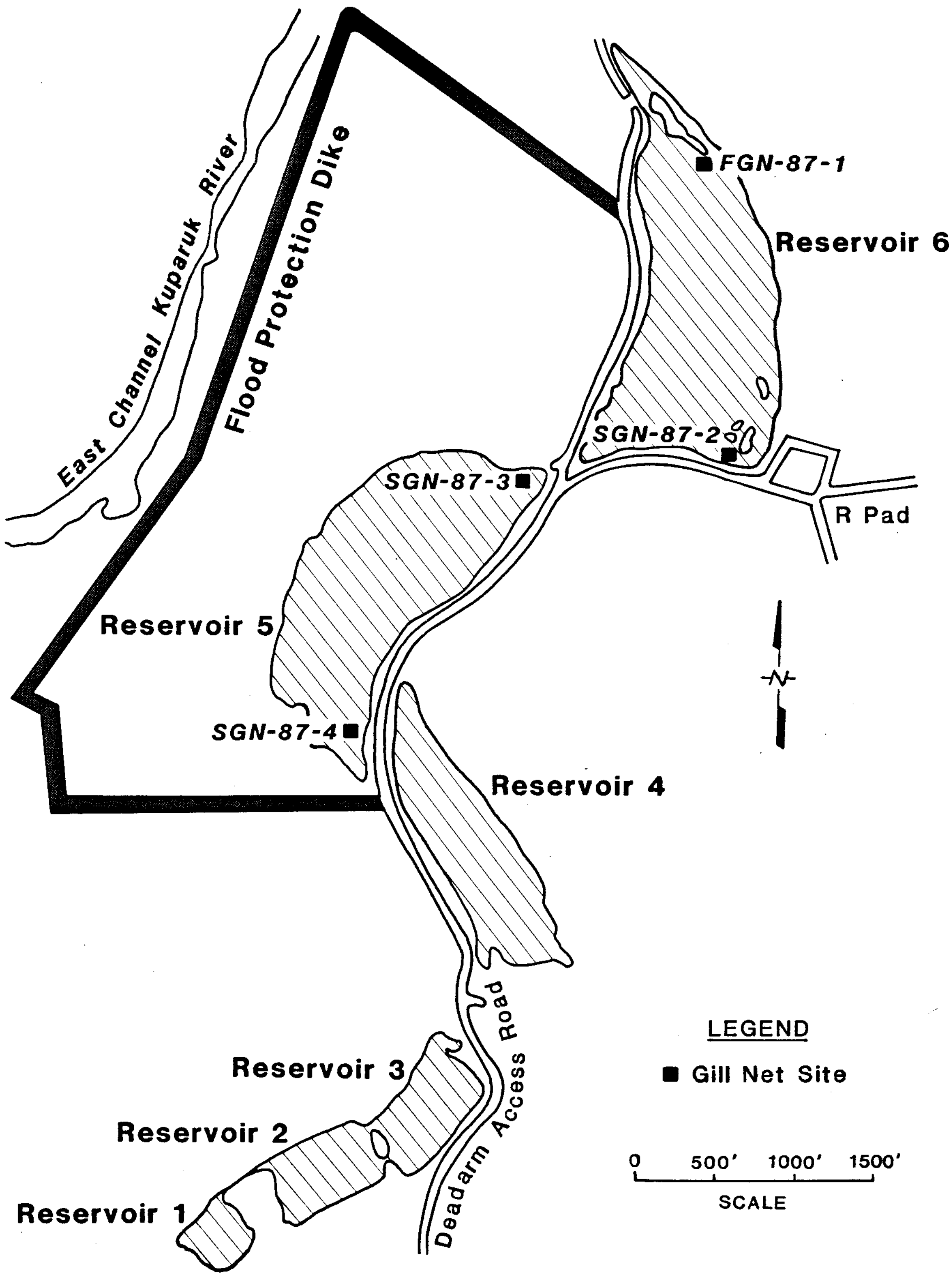
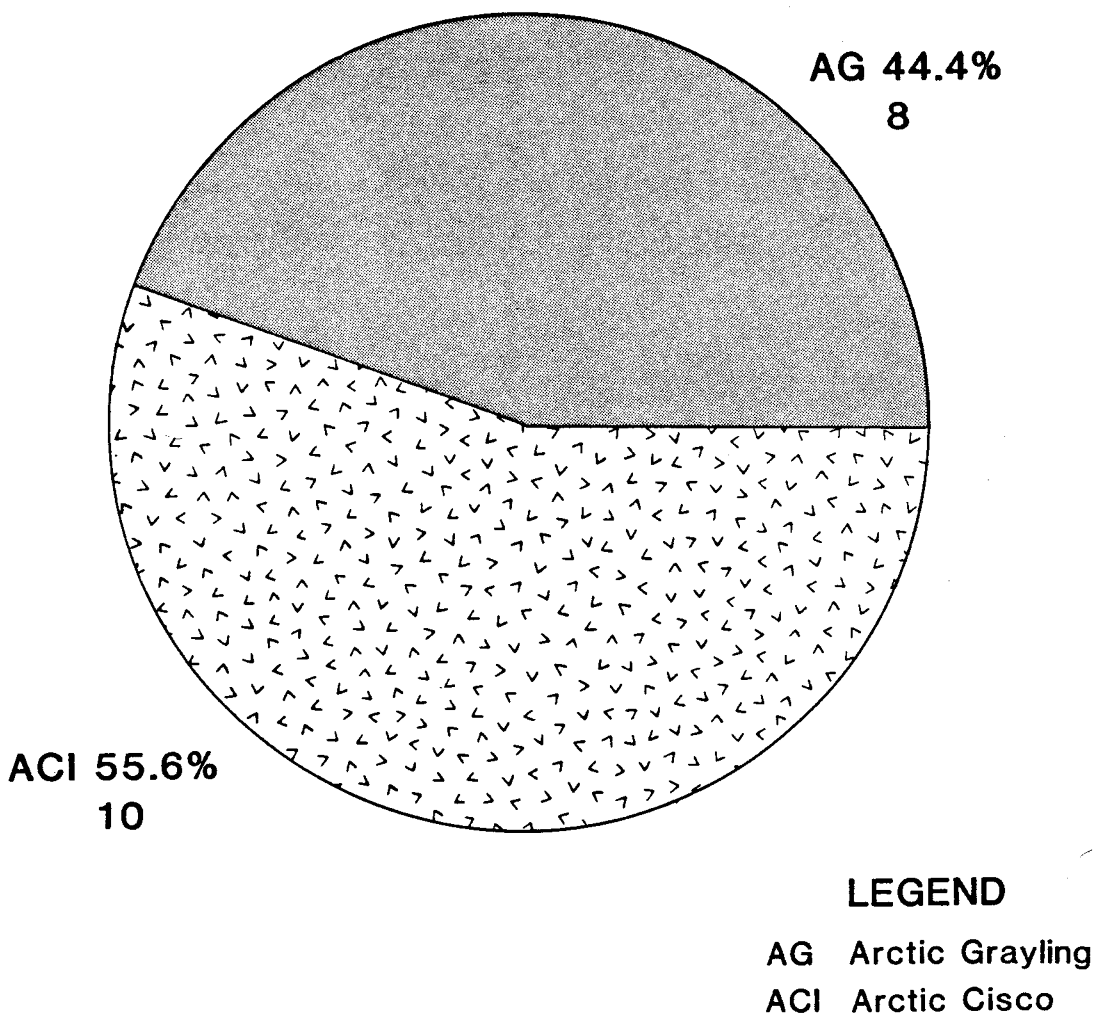


TABLE 7. Summary of fish sampling gear, effort, and catch in 1987 at the Kuparuk Deadarm Gravel Extraction Area, Mid-Beaufort Region, Alaska.

Location Code	Dates	Gear Type	Elapsed Time (hr)	Catch	CPUE (fish/hr)
FGN-87-1	Aug. 11-12	125' variable mesh floating gill net	20	4 arctic cisco	0.2
SGN-87-2	"	125' variable mesh sinking gill net	"	1 arctic cisco 1 arctic grayling	0.1
SGN-87-3	"	"	22	5 arctic cisco	0.23
SGN-87-4	"	"	"	7 arctic grayling	0.32

FIGURE 7

1987 KUPARUK DEADARM SAMPLE CATCH
Species Composition



3.3 Discussion

The fish species found in the flooded gravel mine sites reflect the diversity and abundance of fish occurring in the adjacent source-water streams or rivers. The greatest fish abundance and species richness were found in the mine sites connected to the Sagavanirktok and Kuparuk river systems. These large river systems support several species of freshwater and anadromous fish. It is likely that with time the species richness in the mine sites will increase to include most of those species found in adjacent stream environments. The number of species found in test net sampling at Sag Site C, for example, has increased from two to four during the first 2 yr of sampling. Other species, such as burbot, slimy sculpin, and ninespine stickleback, which are not susceptible to capture by the test nets used in this study, may also be present, although the latter two species should have appeared in the minnow-trap catch if they were abundant at this site.

The gravel mine sites connected to tundra streams (e.g., Kuparuk sites B and D) differ significantly from those sites connected to large river systems because the adjacent source-water streams are limited in the diversity and abundance of fish present (Dew 1981, Moulton 1980). Unlike larger rivers, whose most important habitat characteristic when compared to the smaller tundra streams is the presence of overwintering areas for fish (Adams 1985, Bendock 1977, Schmidt et al. 1987), these small tundra streams (e.g., Ugnuravik River and East Creek) display significant variability in discharge during the summer season, may become intermittent by late summer, and freeze solid during the winter season. Such physical characteristics make them unsuitable for overwintering fish. The exception is the ninespine stickleback, which is found in most of the small tundra streams. The presence of these fish suggests that they may use areas that are unsuitable as overwintering habitat for other species. Sticklebacks are better adapted to the types of habitat available in tundra streams due to their smaller size, greater tolerance to low dissolved oxygen, and high reproductive rate.

As noted in the results section of this report, ninespine sticklebacks were not found in the sites connected to large river systems. This difference can be attributed to the presence of shallow-water habitat with emergent vegetation in tundra stream systems. Such habitat is selected by ninespine sticklebacks during the open-water season. The large river systems do not have similar habitats in the vicinity of the mine sites examined in this study.

The presence of broad whitefish and least cisco in the mine sites connected to tundra stream systems suggests that use of small tundra drainages by anadromous fish may be greater than previously expected. Both such sites are located well upstream of the zone of marine influence. Mine Site D, for example, is located 23 km upstream of the Ugnuravik River mouth. In addition to sites adjacent to tundra streams, mine sites on the larger systems potentially may be colonized by anadromous whitefish from the nearshore Beaufort Sea. Arctic char, on the other hand, are less likely to colonize mine sites other than Sag Site C because the Sagavanirktok River is the only system in the study area with a spawning population of char, although char can enter the Kuparuk River and the tundra streams from the Beaufort Sea. The lack of overwintering habitat in tundra streams probably limits the ability of arctic grayling to colonize the mine sites connected to those systems that drain directly to the Beaufort Sea. Round whitefish also are most likely to occur in those sites connected to large river systems because they are similar to arctic grayling in their low tolerance to salinity and therefore their ability to colonize sites connected to tundra streams draining directly to the Beaufort Sea. Thus, colonization of mine sites connected to such tundra streams will likely be limited to ninespine stickleback, which rapidly colonized the newly created deep lakes, and anadromous whitefish that make excursions into the tundra systems during high-water periods.

Similar tundra stream systems connected to large rivers are known to provide spawning habitat for arctic grayling. Examples include Weir Creek on the Kavik River system and Seabee Creek, a tributary to the Colville River system at Umiat (Craig and Poulin 1975, Hemming 1977). Grayling move into these tundra streams during the spring flood and use these areas as spawning habitat. Grayling fry move out of the tundra streams prior to late summer when flow may become intermittent. Thus, arctic grayling introduced to the mine sites may use adjacent tundra streams for spawning with the mine sites providing the necessary overwintering habitat.

The lack of success in winter fish sampling should not be considered an adequate indicator of the overwinter habitat potential of the sites. The failure of gill nets set under the ice to capture fish is probably due to the low density of fish in relation to the volume of habitat available. The level of fishing effort (e.g., 1 net-night) was minimal but could not be easily increased due to the difficulty in deploying and maintaining the gear under thick ice cover. Another factor in the lack of capture success may be the reduced activity level of fish during the ice-covered season. Given the physical and chemical characteristics of the sites, there is no reason to believe overwinter survival of fish is not possible in any of the mine sites.

Extensive late summer upstream migrations into deep lake overwintering areas have been documented in the upper Kuparuk River system and the Sadlerochit River system (West and Wiswar 1984, Deegan 1988). These documented arctic grayling movements demonstrate a clearly defined pattern of grayling seeking out deep lake or river habitats in late summer and early fall. Arctic grayling will likely respond to the presence of the flooded gravel mine sites in a similar fashion to other deep lakes found on the North Slope.

The ability of the mine sites to support fish populations over time will likely depend on the persistence and seasonal duration of the connection to an adjacent river system, the quality of summer rearing habitat in the mine site, and the quality of overwintering habitat. It is unknown whether the fish species using the mine sites will find suitable spawning habitat in the mine site complex areas.

Stomach analysis indicates that most of the fish captured from the mine sites were finding food items. The arctic grayling in Sag Site C were feeding primarily on terrestrial insects. The whitefish in Sag Site C and Kuparuk Mine Site B were feeding primarily on chironomid (Diptera) larvae. The Mine Site B broad whitefish stomachs contained more chironomid larvae than those from Sag Site C. Food items from Mine Site B broad whitefish also included caddisfly (Trichoptera) larvae and freshwater snails (Gastropoda), which were not found in the broad whitefish from Sag Site C. These data indicate Mine Site B is providing benthic fish food items and a higher diversity of food organisms than Sag Site C. Mine Site B is an older, shallower basin supporting well-established emergent vegetative communities. These characteristics likely contribute to the greater numbers of benthic fish-food organisms found in the fish stomach analysis. The arctic cisco from the Kuparuk Deadarm area were feeding exclusively on zooplankton organisms consisting of Daphnia sp. and three types of copepods. Large numbers of these organisms were found in the arctic cisco stomachs examined.

The chlorophyll-a values from the North Slope pits are equal to or higher than chlorophyll-a concentrations found in phytoplankton in Harding Lake near Fairbanks. LaPerriere (1988) reported that the highest chlorophyll-a value for Harding Lake occurred in May before ice out when she measured 4 ug/L. The summer average for Harding Lake was 2 ug/L.

Values found in the North Slope mine sites are also higher than those found in Charr Lake on Resolute Island (Kalff and Welch 1974). Researchers there reported high chlorophyll-a values from phytoplankton of 1.2 ug/L and average values of 0.8 ug/L. Interestingly, studies in Charr Lake indicated that 80% of the primary production occurred in the periphyton and mosses on the lake bottom.

The high values found on the bottom of Charr Lake suggest that the high chlorophyll-a value found in the Kuparuk Reservoir 6 at the 3.7-m depth (the bottom of the pit) was due to periphyton growth. An alternative explanation for the high value is that the sample measured dead phytoplankton cells that had settled to the substrate.

Summer averages of chlorophyll-a in Toolik Lake were 1.3 ug/L in the photic zone (Hobbie et al. 1986). This level is comparable to levels found in the North Slope mine sites.

Ostrofsky and Rigler (1987) published estimates of chlorophyll-a content from 49 subarctic lakes near Yellowknife, Northwest Territories. Comparisons with their data show that the chlorophyll-a values measured in the North Slope mine sites are slightly lower but within the same order of magnitude as the 49 natural lakes.

Three species of Copepoda and one species of Cladocera were identified in the zooplankton samples collected from the North Slope gravel mine sites. The calanoid copepod Diaptomus sp. was identified in all the sites sampled. This organism is 1.5 mm in length and very similar to a diaptomid found in Old Franks Lake in southeastern Alaska, identified as Diaptomus tyrelli. In the Kuparuk Deadarm sites and Kuparuk Mine Site B another calanoid copepod, Heterocope septentrionalis, was identified in the samples. This organism is 3.5 mm in length and is found in lakes and ponds of Alaska and northern Canada. It has been found previously at West Lake on Fort Greely near Fairbanks, Alaska. The third copepod identified was Cyclops sp. This species was found in samples collected from the Kuparuk Deadarm mine sites. The cladoceran Daphnia sp. was also collected from the Kuparuk Deadarm mine sites.

As shown in the results, the species richness and abundance of zooplankton was greatest in the Kuparuk Deadarm and in Kuparuk Mine Site B. Both of these sites have more littoral habitat than the other sites investigated. For example, Reservoir 6 of the Kuparuk Deadarm has an extensive area of littoral habitat. In addition, Mine Site B is older than the other sites and supports an emergent vegetative community, which may be a factor in increased production at this site. In contrast, the abundance of organisms in the sample from Mine Site D was low in comparison to the other sites. Mine Site D has very little littoral habitat, is relatively new, and has not yet stabilized.

Active migration is responsible for geographic dispersal of species throughout a drainage system. Where there is overland flow, such as on the North Slope of Alaska in the spring, copepods may be dispersed in the resting egg stage and as cysts. Cyclops sp. encysts at the copepodid stage until conditions are favorable for hatching and growth. Cladocerans are easily transported as ephippial eggs. Waterborne transport is the most probable mechanism for colonization of the mine sites, although other dispersal mechanisms cannot be ruled out.

4.0 Site Morphology

4.1 Methods

Depth profiles were determined by sounding with an electronic hand-held, gun-type fathometer. Measurements were taken at 15-s intervals as the boat was operated at a constant slow speed along an identified transect. All depth data were recorded in feet to the nearest whole numbers and later converted to metric equivalents. The perimeter configuration of each site was evaluated from aerial photography (scale: 1 in = 1,500 ft) and topographic maps (scale: 1 in = 500 ft) generated from aerial photography.

4.2 Results

Depth profile transect data are presented in Appendixes J through M. Kuparuk Mine Site D and Sag Site C are similar in nature with steep sides, flat basin floors, depths exceeding 10 m, and very little shoreline development. The perimeters of these sites are generally rectangular. Kuparuk Mine Site B is shallower and has more shoreline development than the preceding sites due to its two-basin configuration. Kuparuk Deadarm Reservoirs 4 and 5 are similar to Sag Site C and Kuparuk Mine Site D with steep sides, relatively flat basin floors, and depths exceeding 10 m. The Deadarm sites have greater shoreline development due to irregularities in the excavation perimeter and a multiple basin configuration. Kuparuk Deadarm Reservoir 6 differs significantly from the other sites because it has extensive areas of littoral habitat (less than 2 m) and greater shoreline development including several small islands and spits. The only sites having significant amounts of littoral habitat as determined from the depth profile data are Kuparuk Reservoir 6 with 41% of the depth readings under 2 m and Kuparuk Mine Site B with 20% of the depths recorded under 2 m. The remainder of the sites possessed less than 10% littoral habitat as determined from the transect data.

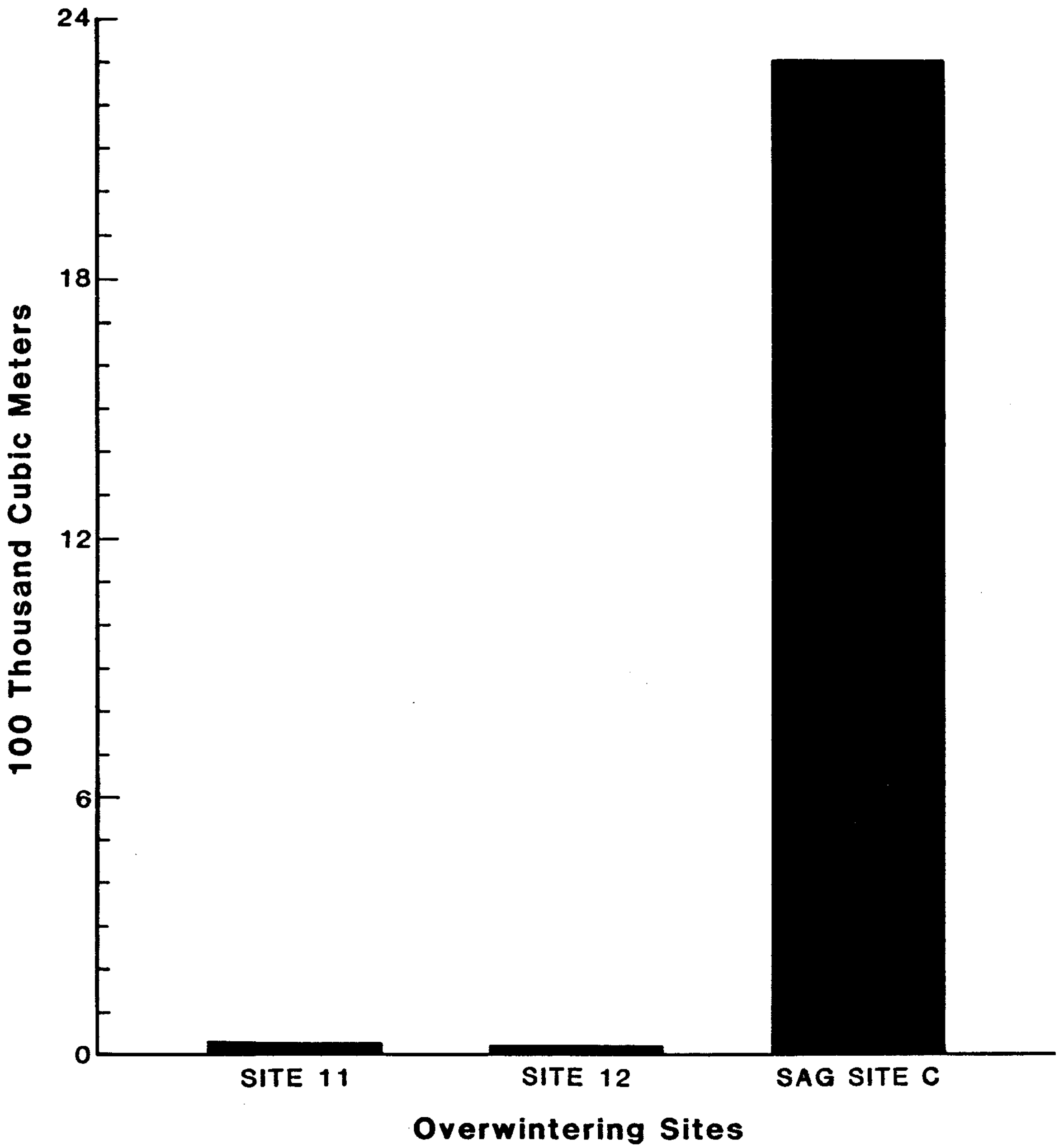
4.3 Discussion

The flooded gravel mine sites examined in this study are unique habitat features in the Mid-Beaufort Coastal Plain Region as their depth exceeds that of other tundra lakes and ponds. Tundra ponds seldom exceed 2 to 3 m in depth. The flooded mine sites examined exceeded 7 m in depth at all sites investigated with five of the seven basins exceeding 10 m in depth. These deep lake basins contain significant quantities of under-ice water. When compared to the existing riverine under-ice water available, the potential of these sites as winter fish habitat is apparent. Recent studies of the lower Sagavanirktok River delta conducted as part of the Endicott Environmental Monitoring Program provided information on the dimensions of known overwintering areas (Adams 1985, Schmidt et al. 1987). The volume of under-ice water in Sag Site C is 88 times greater than that reported for the largest known overwintering areas in the lower Sagavanirktok River delta. Figure 8 compares winter water volumes in Sag Site C and Sites 11 and 12, the two largest overwintering areas identified in the study conducted by Envirosphere Company (Adams 1985).

Four of the artificial lake basins investigated in this study possess limited amounts of shallow-water littoral habitat, an important feature of productive lake environments (Joyce et al. 1980). The two exceptions are Kuparuk Deadarm Reservoir 6 and Kuparuk Mine Site B. These sites meet or exceed the area of littoral habitat recommended for excavation features designed to enhance their suitability for fish production (Joyce et al. 1980). Two of the larger sites investigated (Sag Site C, Kuparuk D) have rectangular perimeter configurations that provide limited shoreline development. The incorporation of islands, spits, and bays in site rehabilitation plans would help to increase shoreline development, another important characteristic of productive lake habitat.

FIGURE 8

HABITAT COMPARISON
SAGAVANIRKTOK RIVER DELTA



5.0 CHEMICAL CHARACTERISTICS

5.1 Methods

Water sampling stations were established near the center of each mine site. Water samples were collected with a Van Dorn sample bottle at the surface or just below the ice surface, at 3-m intervals through the water column, and just above the bottom. Temperature, dissolved oxygen, pH, conductivity, alkalinity, and hardness were determined from the water samples collected at each depth. All water chemistry measurements were determined according to Standard Methods (Sixteenth Edition). Water quality sampling for the six characteristics listed was conducted by ADF&G and USFWS personnel in late August 1986. Winter water quality monitoring for the same six characteristics was conducted at Sag Site C by ARCO Alaska, Inc. Winter water quality monitoring was conducted by ADF&G personnel during late April and early May (1987) at Kuparuk Mine Sites B and D. Open-water sampling was conducted from an inflatable raft while winter sampling was conducted from the ice surface using an ice auger to drill through up to 2 m of ice that had formed on the sites by late winter. Water quality monitoring during the 1987 open-water season was limited to collecting temperature profile data in mid-July and mid-August.

5.2 Results

5.2.1 Sag Site C - The water quality data collected at Sag Site C are presented in Appendix N. The temperature profile remained isothermal with maximum temperatures reaching 8° to 9°C in mid-August. Temperatures during the ice-covered season declined to approximately 1°C by early January and remained stable through the last sampling period in late April. Dissolved oxygen levels remained at or near saturation throughout the open-water and ice-covered season. The pH levels were within the range considered acceptable for fish production and approached levels considered optimum for algal production (pH 7.5). The conductivity levels in Sag Site C were within the range (100-150 umho/cm) reported for ponds and lakes in the Mid-Beaufort Region. The alkalinities measured at Sag Site C were moderate, within the range considered acceptable for fish production. Waters with low alkalinity are generally considered less productive. Hardness levels at Sag Site C are very close to the measured alkalinity levels indicating that the hardness is carbonate in origin with non-carbonate sources contributing minimal levels of hardness.

5.2.2 Kuparuk Mine Site B - The water quality data collected at Kuparuk Mine Site B are presented in Appendix O. The temperature profile at Kuparuk Mine Site B was isothermal on August 20, 1986 and April 30, 1987. Summer maximum temperatures were 1° to 2°C warmer than the larger sites monitored. The temperature profile taken on July 16, 1987 showed a thermal stratification pattern with a surface temperature of 12°C, a thermocline occurring between 2.5 and 3.5 m below the surface, and a temperature of 6°C below the thermocline. Dissolved oxygen concentrations were slightly lower than the other sites but well within the range suitable for fish production. Conductivity, pH, hardness, and alkalinity levels were also within the range of acceptable values and similar to those reported for ambient water quality in the North Slope Region.

5.2.3 Kuparuk Mine Site D - The water quality data collected at Kuparuk Mine Site D are presented in Appendix P. Temperature profiles remained isothermal with maximum temperatures of 9° to 9.5°C recorded on August 20, 1986. Dissolved oxygen concentrations remained at or near saturation during both the open-water and ice-covered season. The pH levels were within the range considered acceptable for fish production. The conductivity levels in Mine Site D were up to 4 times higher than those measured at the other sites but still within the range of values acceptable for fish production. The hardness levels in Mine Site D were higher than the alkalinity levels, indicating non-carbonate sources of hardness. Moderate levels of alkalinity were measured in Mine Site D waters.

5.2.4 Kuparuk Deadarm - Temperature profiles from the surface to a depth of 3 m were taken in Kuparuk Deadarm Reservoirs 5 and 6 on August 12, 1987. The temperature in Reservoir 5 was isothermal at 9°C between the surface and the 3-m depth. The temperature in Reservoir 6 was isothermal at 8°C between the surface and the 3-m depth.

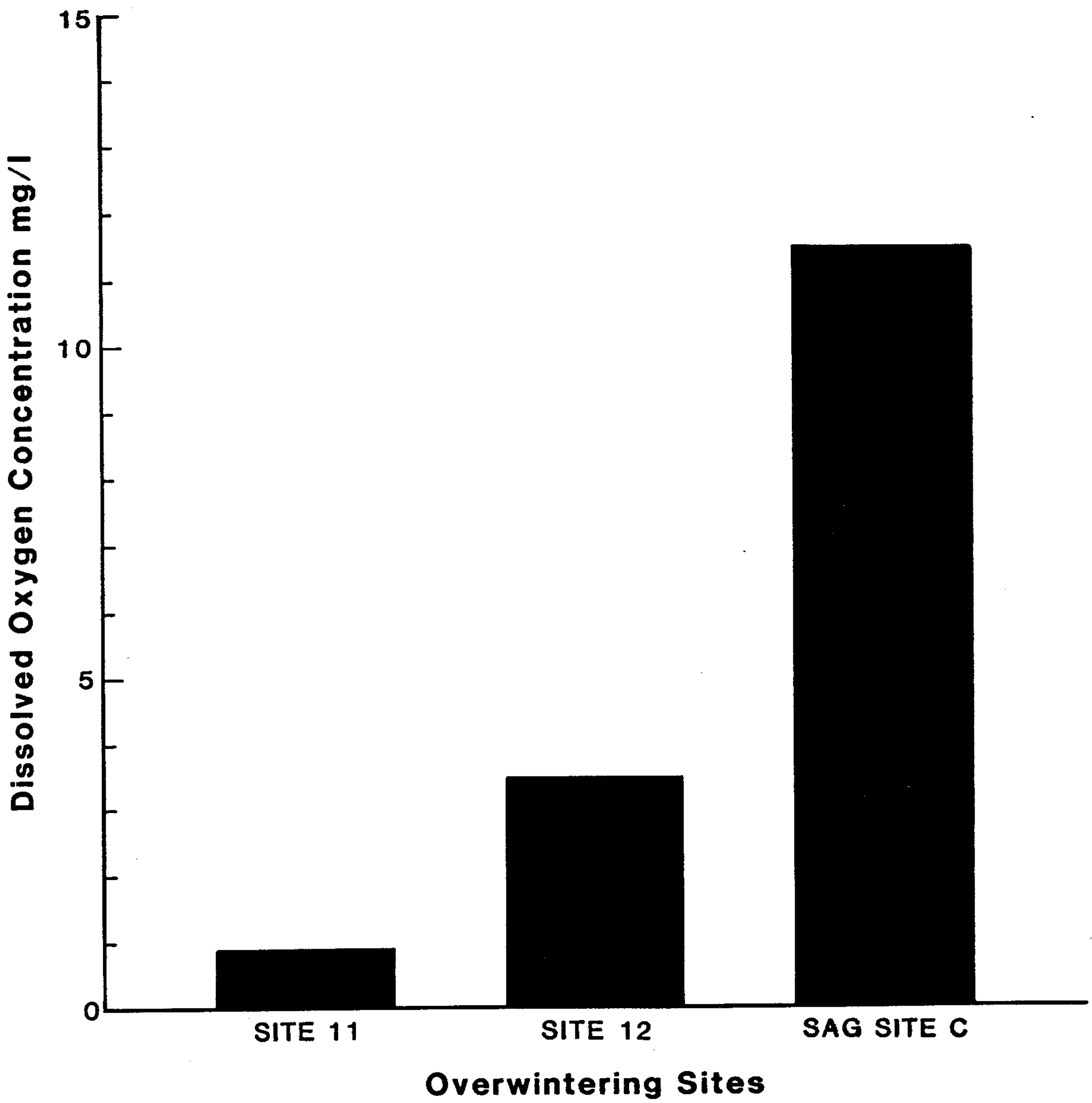
5.3 Discussion

The three gravel mine sites monitored during the open-water season and late winter maintained chemical characteristics suitable to support fish. All sites monitored, with the exception of Kuparuk Mine Site B, had isothermal temperature profiles. The lack of a thermal stratification pattern typical of other arctic and subarctic lake systems can be attributed to low ambient temperatures and persistent wind conditions preventing thermal stratification from developing. Kuparuk Mine Site B is a smaller basin located in a more wind-sheltered area. The combination of its reduced wind-exposed surface area and greater shelter from wind-generated mixing action contributes to the development of thermal stratification at this site. Summer maximum temperatures in Kuparuk Mine Site B are 1° to 2°C higher than those recorded at the other sites. Mine Site B is a shallower basin with less wind-exposed surface area, which promotes increased summer warming.

The dissolved oxygen levels remained at or near saturation throughout the ice-covered season at all sites sampled. The high dissolved oxygen concentrations result from consistent winds, which promote increased surface exchange, and the higher solubility of oxygen under low ambient temperatures. The winter dissolved oxygen concentrations at the flooded gravel mine sites are higher than adjacent riverine areas used by overwintering fish. In a recent study of the Sagavanirktok River Delta area, low dissolved oxygen concentrations were identified as a cause of fish mortality (Adams 1985). The average winter dissolved oxygen concentration in Sag Site C when compared to the two largest known fish overwintering areas (Sites 11 and 12) in the Sagavanirktok River Delta, reveal that concentrations of dissolved oxygen are 3 to 12 times higher in the flooded mine sites than in riverine areas (Figure 9). In a study conducted on the Colville River, eight overwintering sites were sampled during late winter, and dissolved oxygen concentrations ranged from 0.6 ppm to 4.6 ppm (Bendock 1980). It is likely that fish in North Slope river systems would select adjacent flooded mine site habitat due to the favorable chemical characteristics if mechanisms for access were available. Temperatures in the Sagavanirktok River Delta overwintering areas were at or below 0°C at most sites investigated (Adams 1985). Late winter water temperatures in Sag Site C were at or near 1°C. The warmer water temperatures in the flooded gravel mine sites may also be a factor favoring the selection of these sites as winter habitat.

FIGURE 9

DISSOLVED OXYGEN COMPARISONS SAGAVANIRKTOK RIVER DELTA



6.0 SUMMARY AND CONCLUSIONS

Large material sites excavated to provide gravel for North Slope oil and gas development are likely to become deep lakes at the conclusion of their useful lives as gravel material sources. The existing excavations, if flooded, will create 324 ha (800 ac) of lake habitat. Each of the flooded sites investigated have been colonized by two or more species of fish. The species richness and fish abundance is greatest in the sites connected to large river systems with overwintering habitat. Those sites connected to small tundra streams were found to be colonized by ninespine stickleback and anadromous whitefish that occur in nearshore marine habitats during the open-water season. Physical and chemical measurements indicate that flooded mine sites provide suitable overwintering habitat for fish. When connected to adjacent riverine systems the sites can substantially increase the quantity and quality of available winter habitat. Chlorophyll-a measurements indicate the standing crop of photosynthetic organisms in the flooded mine sites is comparable to waterbodies in Interior Alaska and the Canadian Sub-Arctic Region. Four of the seven gravel mine site basins investigated lacked littoral habitat, an important factor for lake productivity and the development of benthic communities. Shoreline features such as islands, points, and bays that increase lake habitat diversity are lacking in the large, rectangular-shaped material sites.

7.0 RECOMMENDATIONS

7.1 Recommended Priorities for Future Study

In accordance with the general objectives set forth in Section 1.2 of this report, future research on flooded gravel mine sites on Alaska's North Slope will be directed toward understanding the physical, chemical, and biological characteristics that make such sites suitable for use by fish and wildlife and applying this knowledge to design of new sites and rehabilitation of existing sites. General tasks to achieve this goal include assessing the long-term biological changes that follow mine-site rehabilitation and associated habitat or fish-population manipulation, further defining the contribution of primary production in supporting fish and wildlife use of flooded pits, comparing fish growth rates between various types of pits and various rehabilitation treatments, examining wildlife use of flooded mine sites, and developing overall rehabilitation guidelines and typical pit designs for future application to North Slope projects.

7.2 Recommendations for Rehabilitation of Existing Sites

(1) Inlet and outlet channel connections to adjacent rivers and streams should be constructed and maintained to allow for fish movement throughout the open-water season. This would allow greater utilization of the overwinter habitat provided by the pits and access to spawning and rearing habitat in the adjacent stream or river environment during the open-water season. Individual pit areas in sites having multiple basins should be connected to each other by channels in a similar manner to allow access to the greatest diversity of habitats available in the pit complex and the adjacent riverine environment.

(2) The amount of littoral habitat should be expanded in most of the sites investigated. Given the depth of the sites, the most effective method of expanding the shallow-water area is excavation outside the existing site perimeter. Water depths of 1 to 3 m covering 25% of the areal extent of the pit complex are recommended.

(3) The shoreline complexity of the sites should be increased. The construction of islands, spits, and bays using overburden or perimeter berm material would increase the complexity of existing shorelines and increase habitat diversity.

(4) For those sites connected to small tundra streams where colonization by freshwater fish is likely to be limited, a fish stocking or transplant program should be implemented. It appears that suitable overwintering, spawning, and rearing habitat is available in the newly created lakes and adjacent streams, and that fish introduced to the mine sites may use these habitats in a similar manner to other stream and deep lake environments on the North Slope.

7.3 Specific Recommendations for Future Study

(1) A population estimate should be conducted for arctic grayling in Sag Site C. Information on the size structure of the fish population in this lake should be gathered with emphasis on determining if spawning is occurring within the mine site or if recruitment is dependent upon movement of fish into the site from the Sagavanirktok River system. Tagged fish should be monitored to document overwinter use of the site. The shallow water area excavated in the fall of 1987 should be monitored to determine the extent of its use by fish.

(2) Limnological sampling should be continued on selected sites with emphasis on primary production.

(3) The lower Putuligayuk River complex should be investigated. Fish species presence and basic water quality data should be gathered to aid in evaluating this area as aquatic habitat.

(4) Additional limnological sampling, with emphasis on winter dissolved oxygen concentrations, should be conducted in the Kuparuk Deadarm reservoirs, along with additional fisheries sampling and collection of physical data on Reservoirs 1-3.

(5) Data collection should be expanded to Kuparuk Site C as time allows.

(6) A program for sampling benthic invertebrates and documenting substrate materials in the flooded gravel mine sites should be developed.

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9.0 APPENDICES

APPENDIX A

Age, length, and sexual condition of 1986 sample catch at Sag Site C

Species	Fork Length (mm)	Sex/Maturity	Age (yr)
Arctic grayling	214	male immature	4+
Arctic grayling	228	male immature	5+
Arctic grayling	239	female immature	5+
Arctic grayling	241	female immature	5+
Arctic grayling	241	female immature	6+
Arctic grayling	243	female immature	5+
Arctic grayling	248	female immature	6+
Arctic grayling	253	female immature	5+
Arctic grayling	255	female immature	5+
Arctic grayling	258	male mature	5+
Arctic grayling	262	male mature	6+
Arctic grayling	264	female immature	6+
Arctic grayling	266	male immature	6+
Arctic grayling	271	female immature	6+
Arctic grayling	273	female immature	6+
Arctic grayling	273	male mature	6+
Arctic grayling	278	male immature	6+
Arctic grayling	281	male mature	7+
Arctic grayling	284	male mature	7+
Arctic char	168	unidentified immature smolt	3+
Arctic char	490	female nonspawner	8+

APPENDIX B

Size and age distribution of Sag Site C arctic grayling (1986)

Age (yr)	Number of fish	Mean length (mm)	Range (mm)	Number of mature fish
4+	1	214	214	0
5+	7	245	228-255	2
6+	9	264	241-273	3
7+	2	283	281-284	2

APPENDIX C

Stomach contents of Sag Site C arctic grayling (1986)

Taxon	Comment
Copepoda	two types identified
Trichoptera	caddisflies
Diptera	
Tipulidae	7 crane fly larvae
Tabanidae	horse flies
Chironomidae	midge larvae
Coleoptera	beetles
Hymenoptera	small ant

APPENDIX D

Length, sex, and stomach fullness of 1987 test net catch at Sag Site C

Species	Length (mm)	Sex	Stomach fullness*
Arctic grayling	225	male	3/4
Arctic grayling	230	male	1/2
Arctic grayling	338	male	4/4
Arctic grayling	242	male	0
Arctic grayling	245	female	1/4
Arctic grayling	258	male	1/4
Arctic grayling	260	female	3/4
Arctic grayling	260	female	1/2
Arctic grayling	260	female	3/4
Arctic grayling	270	female	3/4
Arctic grayling	275	female	1/4
Arctic grayling	280	female	1/4
Arctic grayling	283	male	4/4
Arctic grayling	285	female	4/4
Arctic grayling	285	female	4/4
Arctic grayling	290	male	4/4
Arctic grayling	295	male	1/2
Arctic grayling	295	female	1/4
Broad whitefish	445	female	0
Round whitefish	320	female	0
Round whitefish	327	male	0
Arctic char	470	female	0 (very thin)

* Stomach fullness is subjective rating based on external examination with a rating of 0 meaning empty, 4/4 meaning full, and G meaning gorged or in a distended condition greater than full.

APPENDIX E

Stomach contents from Sag Site C sample catch (1987)

Fish Species/ Sample	Taxon	Number of food items	Comment
Broad whitefish			
Sample #1	Diptera		
	Chironomidae	335	midge larvae
	Tipulidae	24	crane flies
	Simulidae	3	black flies
Round whitefish			
Sample #1	Diptera		
	Chironomidae	4	midge larvae
	Tipulidae	3	crane flies
Arctic grayling			
Sample #1	Diptera	120+	insect parts, primarily terrestrial flies
Sample #2	Diptera	800-1,200 (estimate)	insect parts including chironomid (midge) pupae, simulid (black fly) adults, and other Diptera adults
Sample #3	Diptera	700 (estimate)	Primarily terrestrial insect parts consisting of insect bodies, wings, head parts, whole chironomids, etc.

APPENDIX F

Kuparuk Mine Site B sample catch (1987) and fish stomach analysis

1. Length, sex, maturity, and stomach fullness

Species	Length (mm)	Sex/Maturity	Stomach fullness
Broad whitefish	384	male/immature	1/4
	325	"	1/4
	392	"	3/4
	315	"	1/4

APPENDIX F (continued)

2. Stomach analysis

Fish Species/ Sample	Taxon	Number of food items	Comment
Broad whitefish			
Sample #1	Diptera		
	Chironomidae		midge larvae
	Chironomini and Tanytarsini	650	larvae, including bloodworms
	Trichoptera	45	caddisfly larvae
	Gastropoda	18	fresh water snails
Sample #2			
	Diptera	1	terrestrial flies
	Chironomidae	2,500-3,000	midge larvae
	Trichoptera	10	caddisfly larvae

APPENDIX G

Length, weight, sex, maturity, and stomach fullness of Kuparuk Deadarm Reservoirs 5 and 6 sample catch (1987)

1. Reservoir 6

Species	Length (mm)	Weight (g)	Sex/ Maturity	Stomach fullness
Arctic grayling	184	100	F/mature	3/4
Arctic cisco	381	700	F/immature	1/2
" "	394	700	F/developing	3/4
" "	368	700	F/developing	3/4
" "	368	700	M/developing	1/4
" "	425	900	F/developing	3/4

2. Reservoir 5

Species	Length (mm)	Weight (g)	Sex/ Maturity	Stomach fullness
Arctic cisco	393	800	F/developing	1/2
" "	381	750	M/developing	1/2
" "	381	700	M/prespawning	--
Arctic grayling	292	300	F/developing	trace
" "	114	--	immature	--
" "	114	--	"	--
" "	114	--	"	--
" "	114	--	"	--

APPENDIX H

Kuparuk Deadarm Reservoirs 5 and 6 fish stomach sample analysis

1. Reservoir 6

Arctic Cisco	
Sample #1 = 2,150 organisms (estimated)	
Cladocera	
primarily broken _Daphnia_ sp.	100%
Sample #2 = 275 organisms (estimated)	
Cladocera	
Daphnia sp.	100%
Sample #3 = 460 organisms (estimated)	
Cladocera	
Daphnia sp.	20%
Copepoda	
Diaptomus sp.	80%
Sample #4 = 1,800 organisms (estimated)	
Copepoda	
Diaptomus sp.	100%
Sample #5 = 1,950 organisms (estimated)	
Cladocera	
Daphnia sp.	100%

2. Reservoir 5

Arctic cisco
- Sample #1
  - Cladocera (numerous)
    - _Daphnia_ sp. - well digested
- Sample #2
  - Cladocera (numerous)
    - _Daphnia_ sp. - well digested

Arctic grayling
- Sample #1
  - unidentifiable zooplankton parts - stomach contained few food items

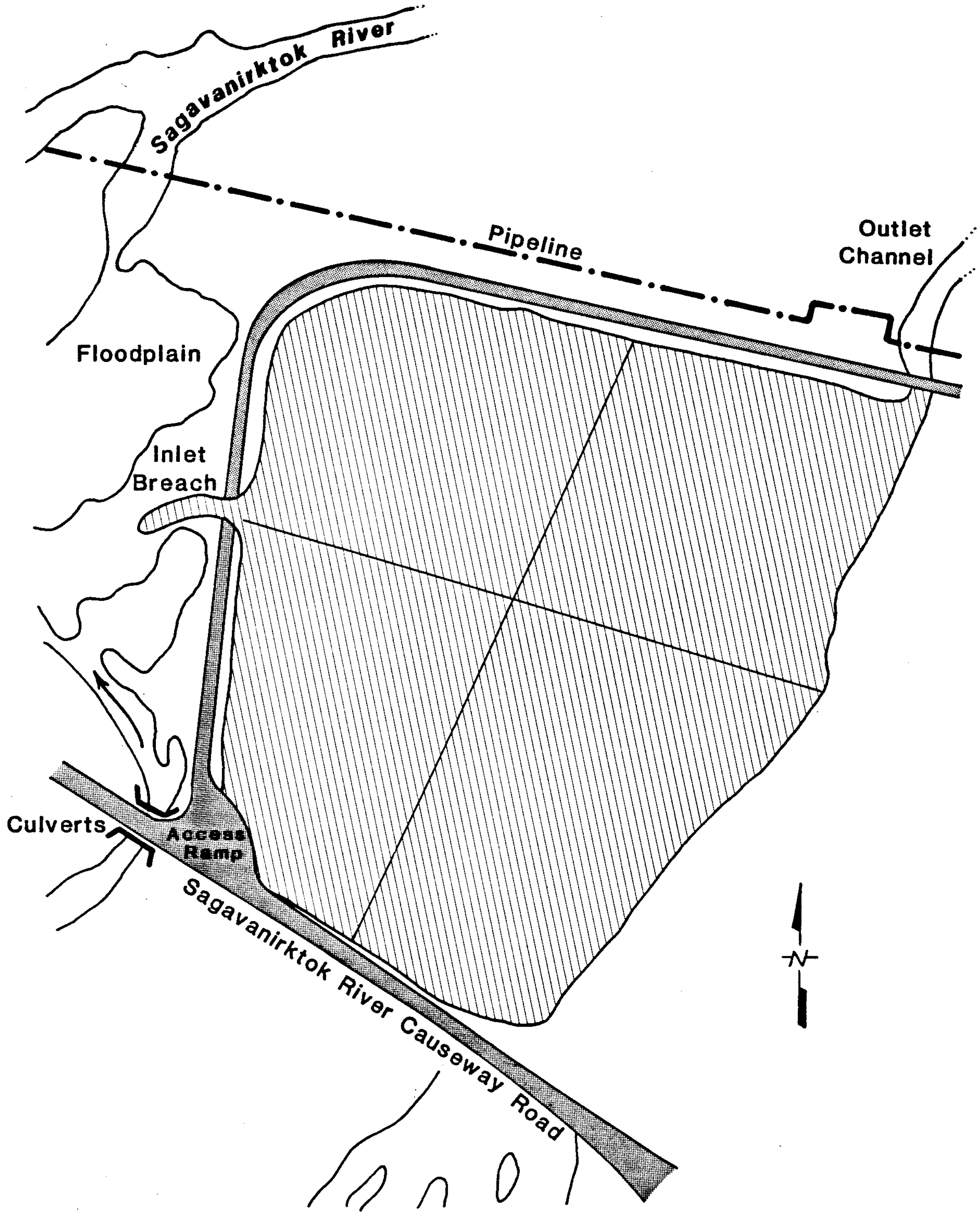
APPENDIX I

Chlorophyll-a concentrations for flooded gravel mine sites during mid-August 1987, Mid-Beaufort Region, Alaska

Sample Location	Sample Depth (m)	Chlorophyll-a (ug/L)
Sag Site C	surface	too turbid to measure
Sag Site C	surface	1.70
Sat Site C	bottom	1.06
Sag Site C	4.5	1.75
Kuparuk Deadarm		
Reservoir 5	surface	1.07
Reservoir 5	surface	0.86
Reservoir 5	surface	2.23
Kuparuk Deadarm		
Reservoir 6	3.7	18.33
Reservoir 6	surface	1.20
Reservoir 6	surface	1.11
Reservoir 6	surface	1.22
Reservoir 6	1.5	1.84
Kuparuk Mine Site B		
Area B	0.3	3.05
Area A	surface	7.37
Area B	surface	3.83
Area A near shore	surface	5.32
Kuparuk Mine Site D in eroded area of Charlie Creek	surface	2.21
Kuparuk Mine Site D	surface	0.88
Kuparuk Mine Site D	surface	1.57
Kuparuk Mine Site D	surface	1.70

APPENDIX J

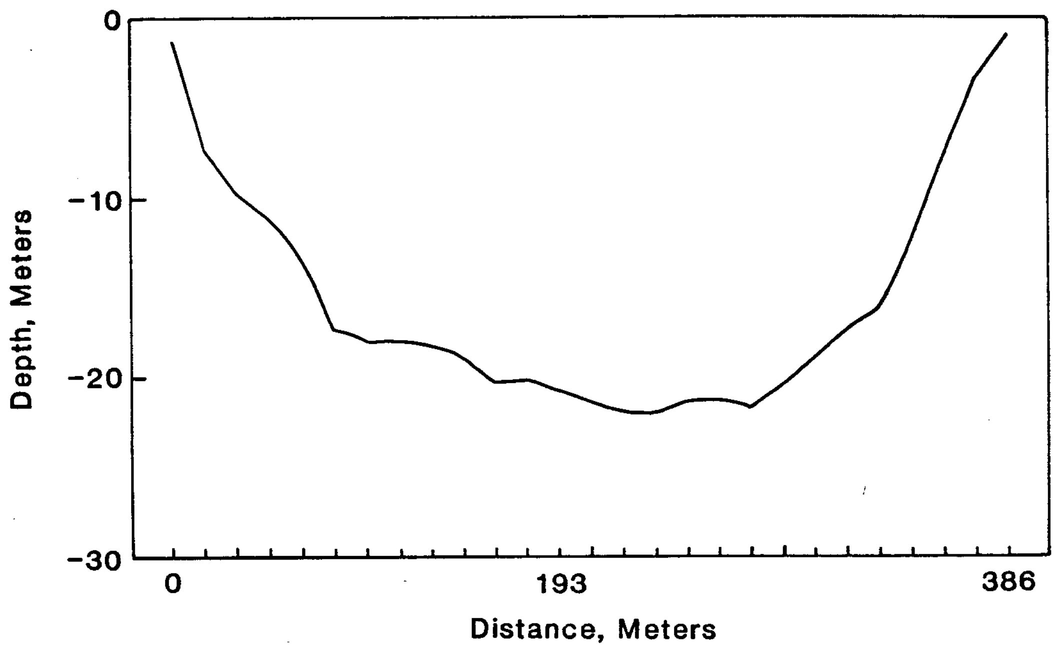
SAG SITE C
Depth Profile Transect Locations



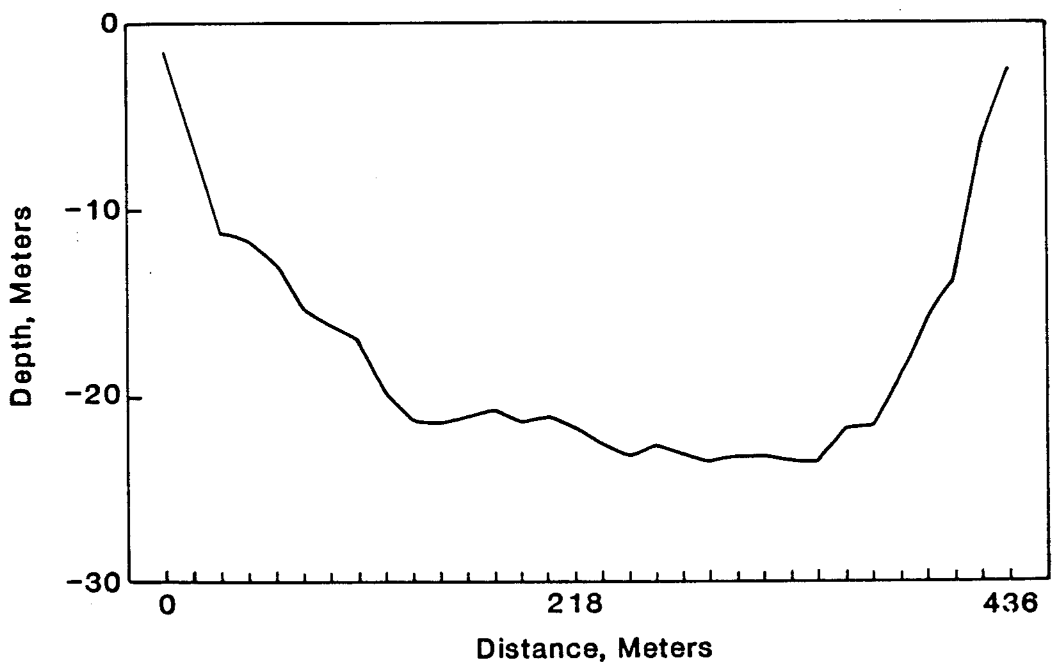
APPENDIX J

SAG SITE C

DEPTH PROFILE, EAST WEST

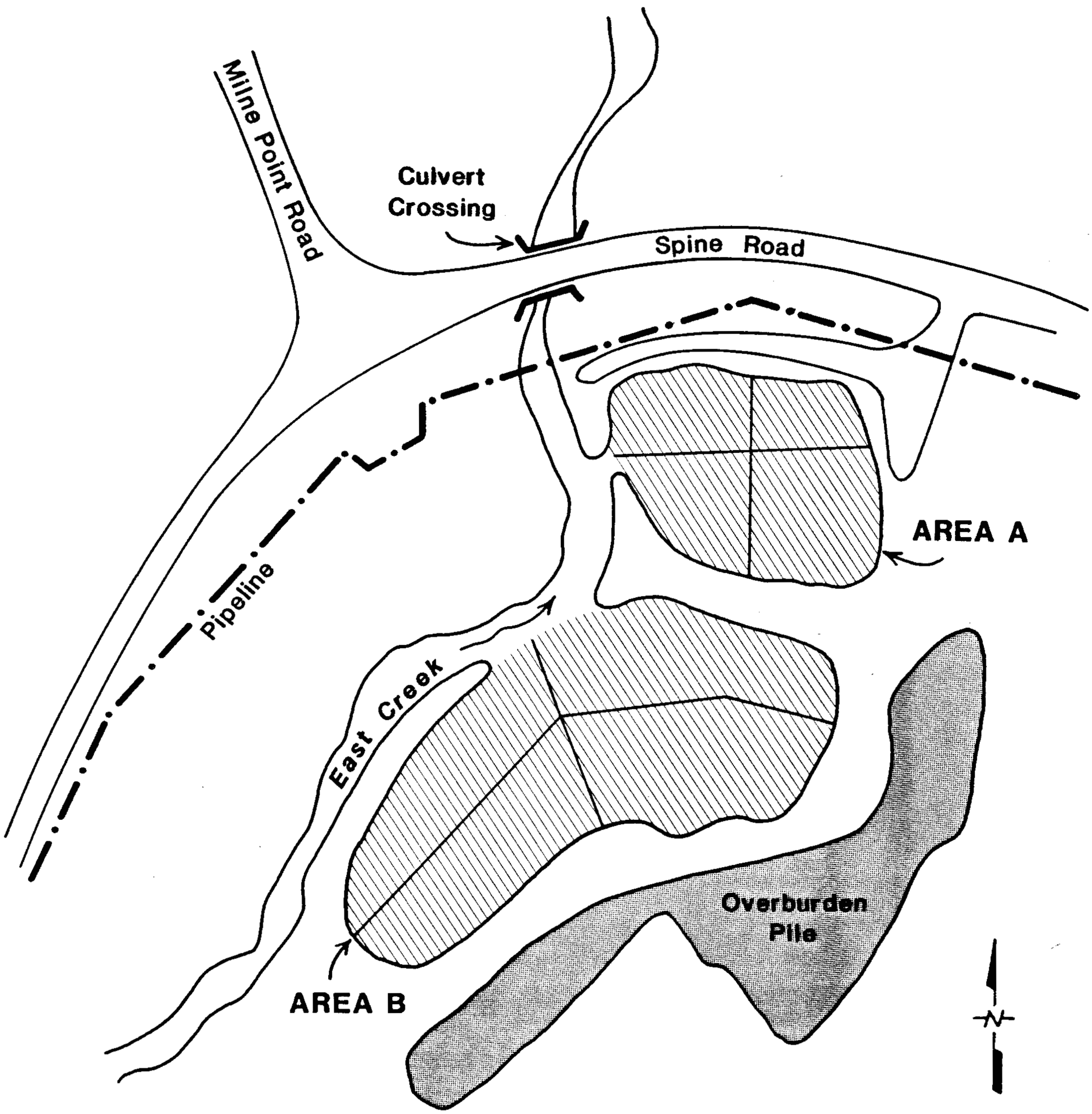


DEPTH PROFILE, NORTH SOUTH



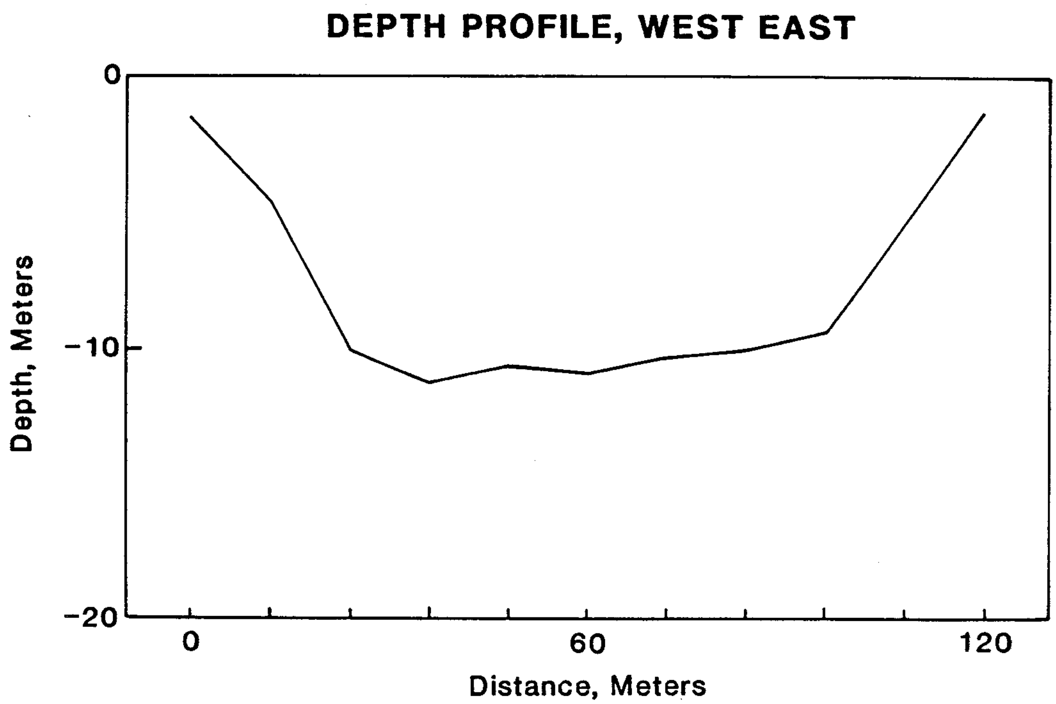
APPENDIX K

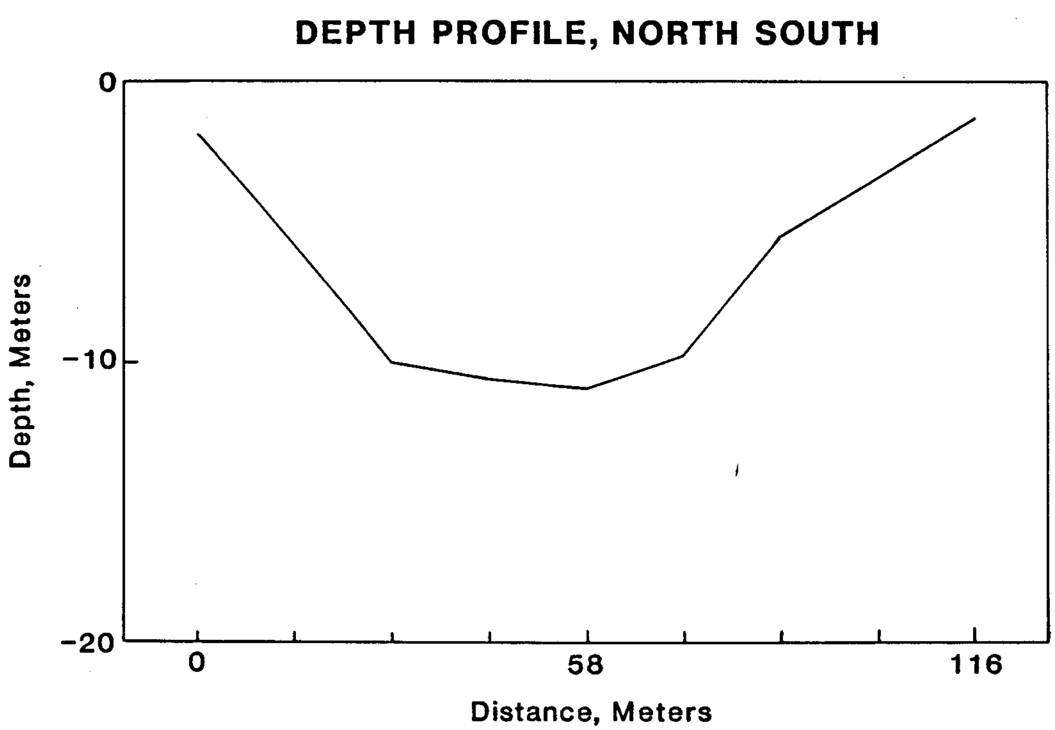
KUPARUK MINE SITE B
Depth Profile Transect Locations



APPENDIX K

KUPARUK MINE SITE B "AREA A"

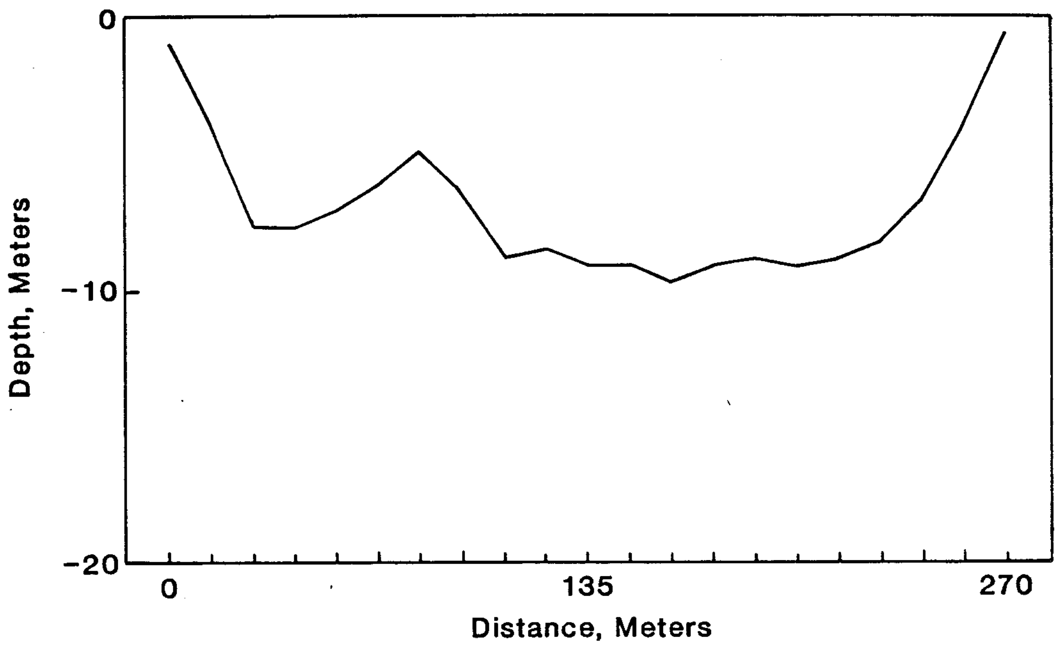




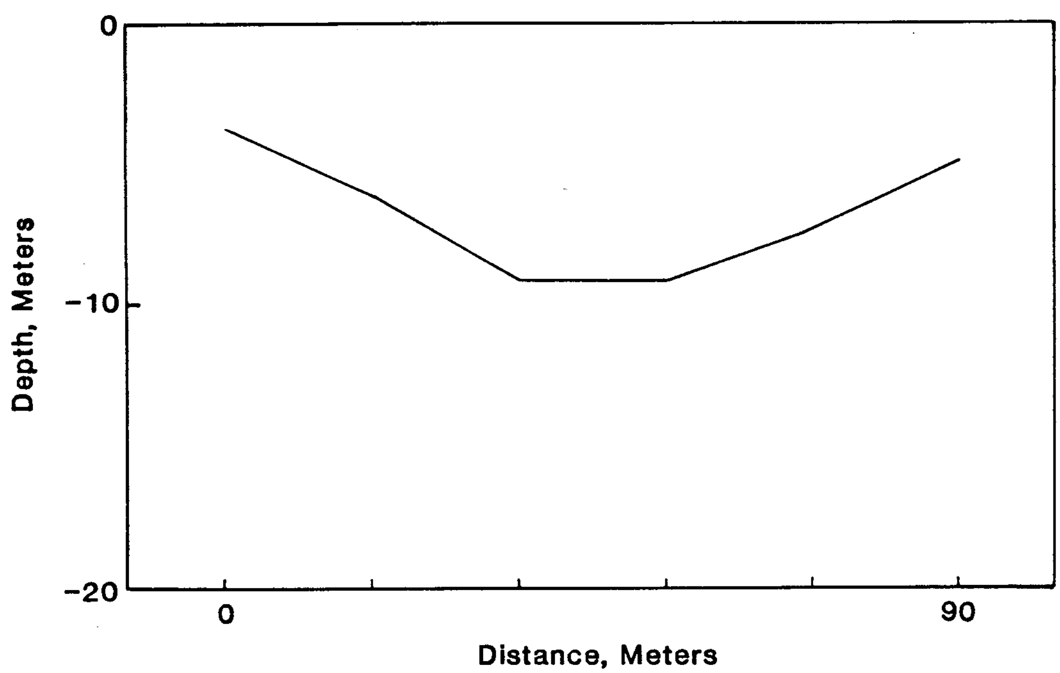
APPENDIX K

KUPARUK MINE SITE B "AREA B"

DEPTH PROFILE, LONG AXIS SOUTH NORTH

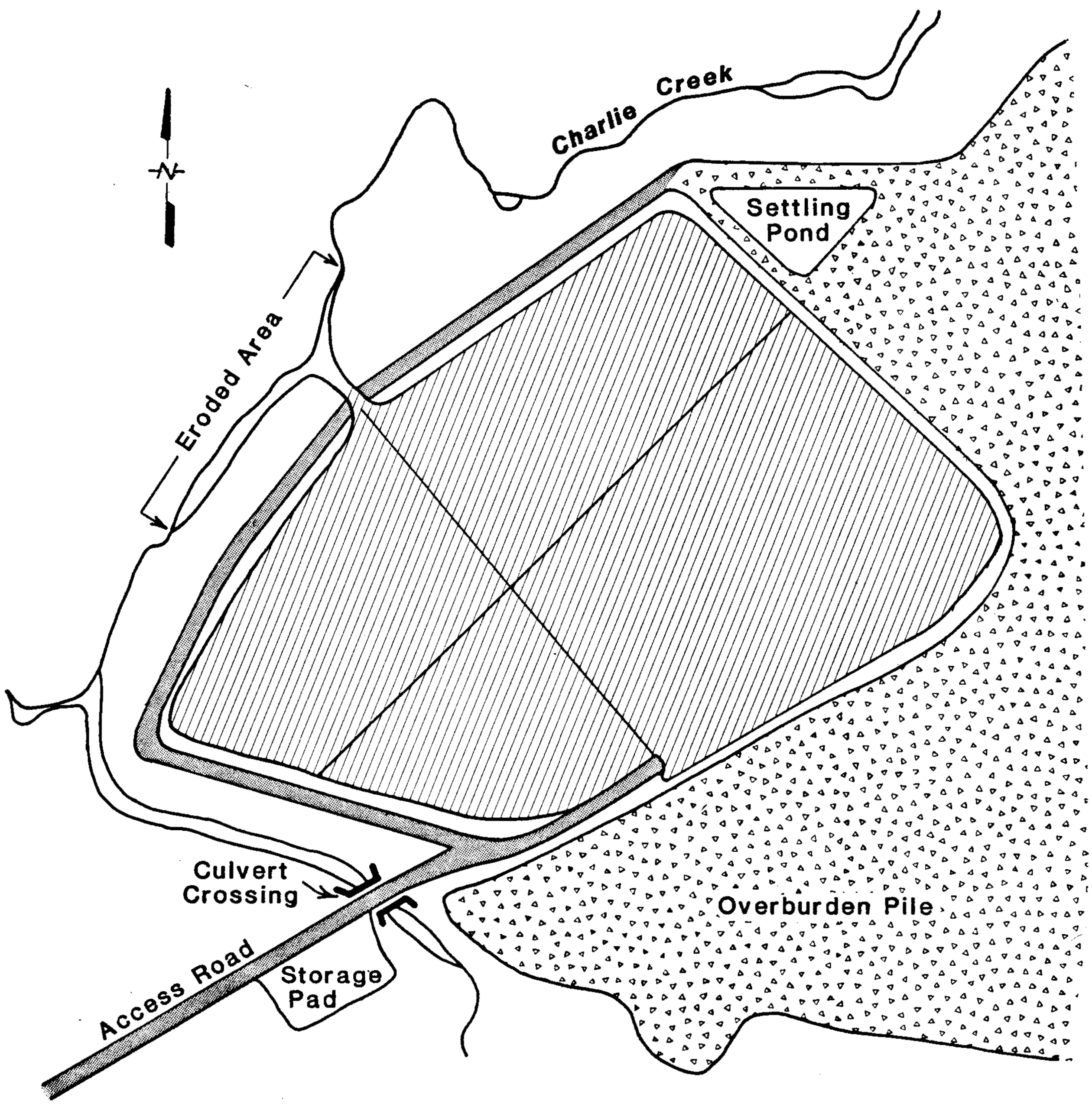


DEPTH PROFILE, SHORT AXIS NW SE



APPENDIX L

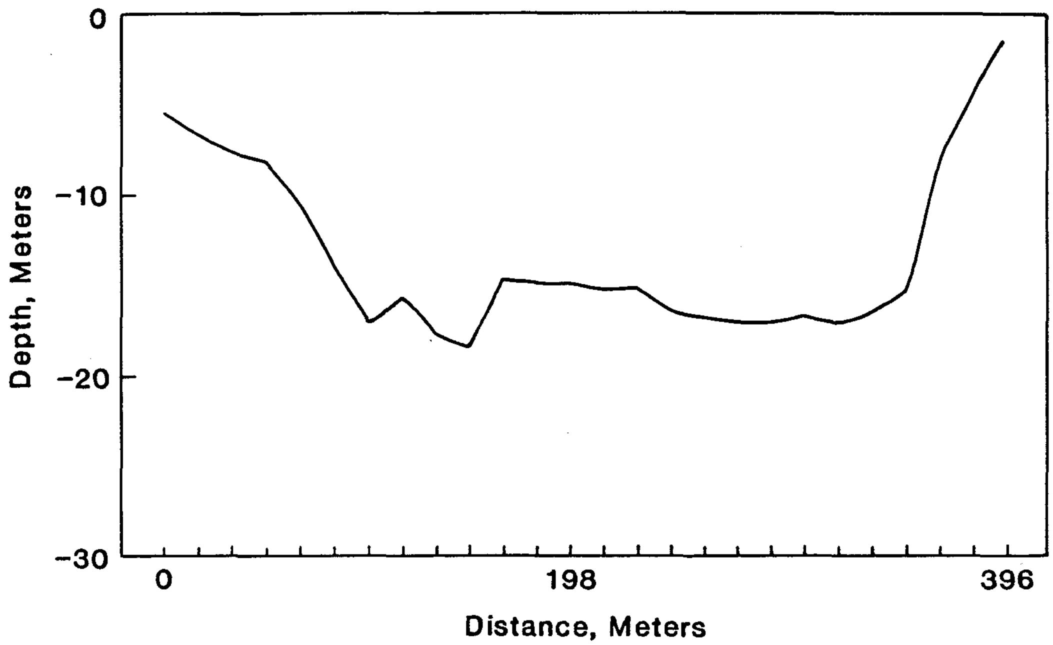
KUPARUK MINE SITE D
Depth Profile Transect Locations



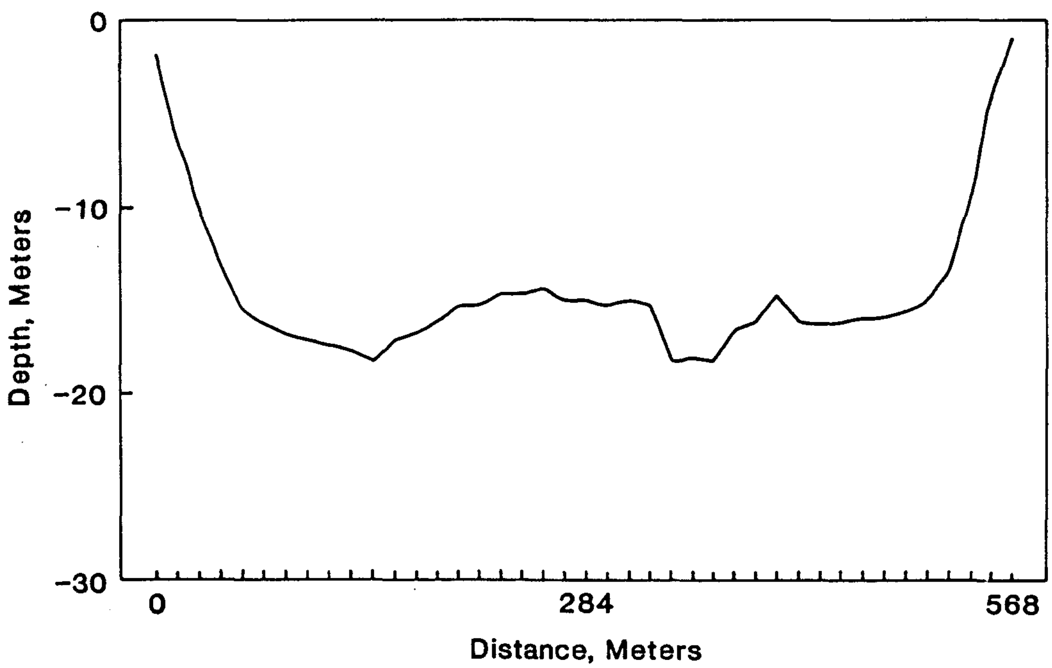
APPENDIX L

KUPARUK MINE SITE D

DEPTH PROFILE, WEST EAST

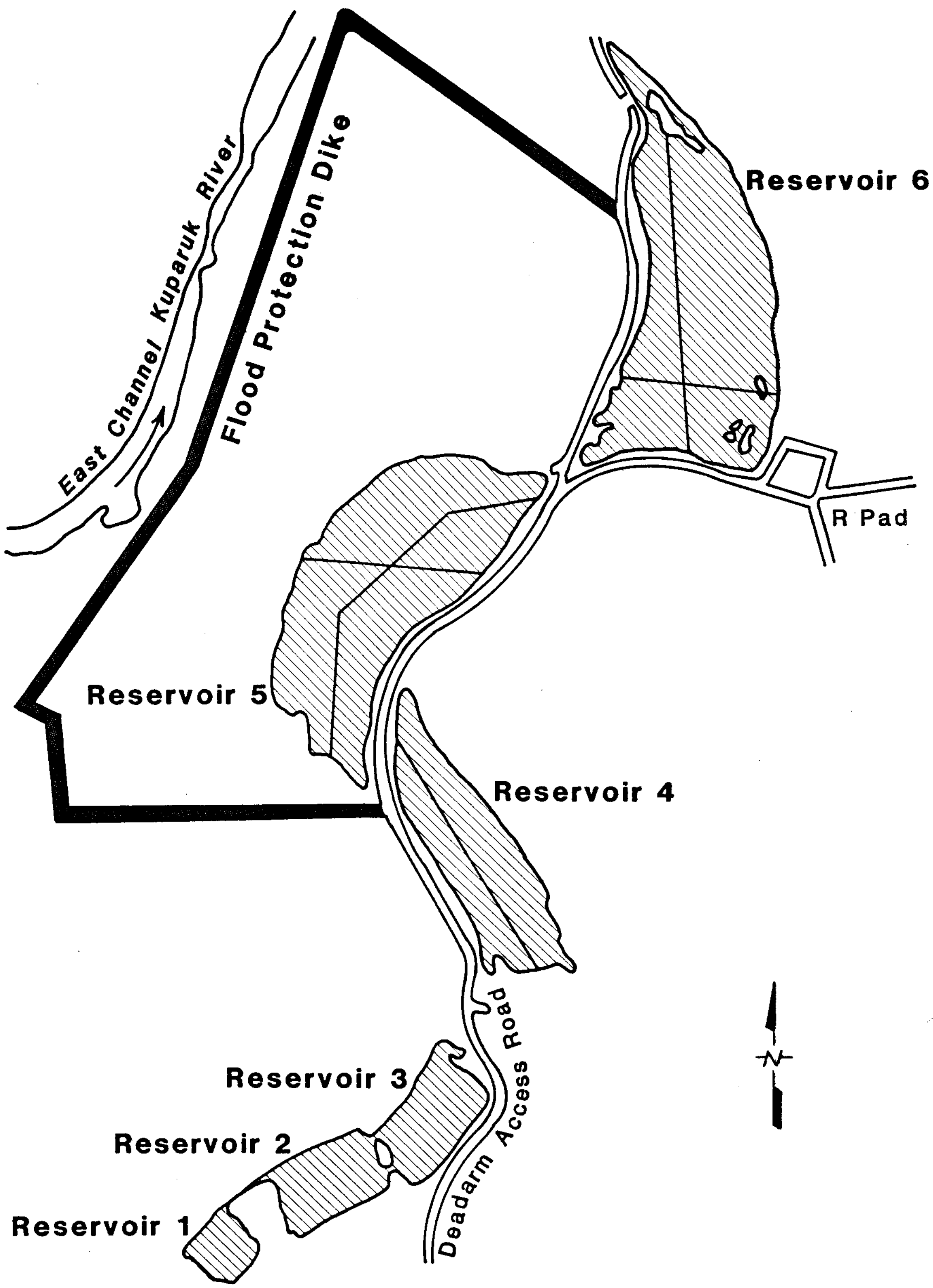


DEPTH PROFILE, SOUTH NORTH



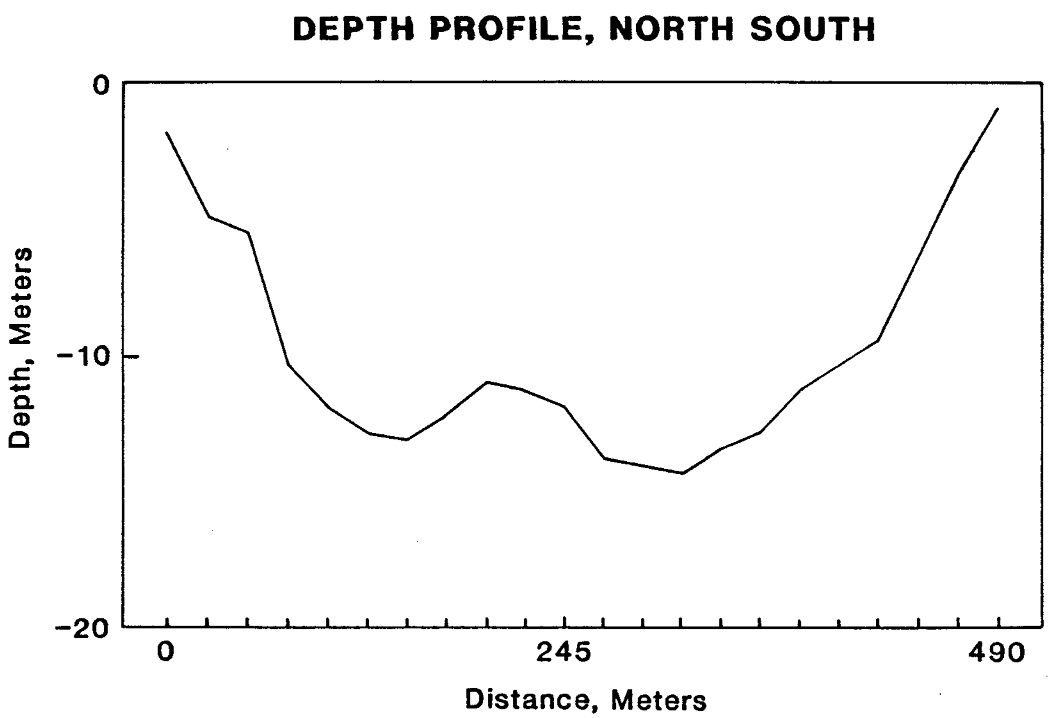
APPENDIX M

KUPARUK DEADARM
Depth Profile Transect Locations



APPENDIX M

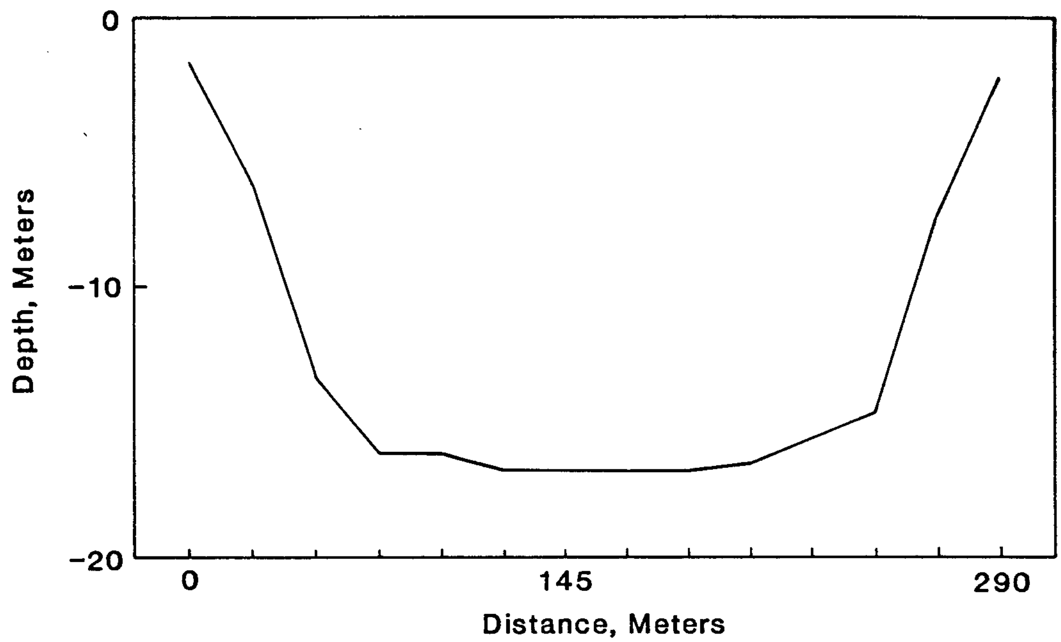
KUPARUK DEADARM "RESERVOIR 4"



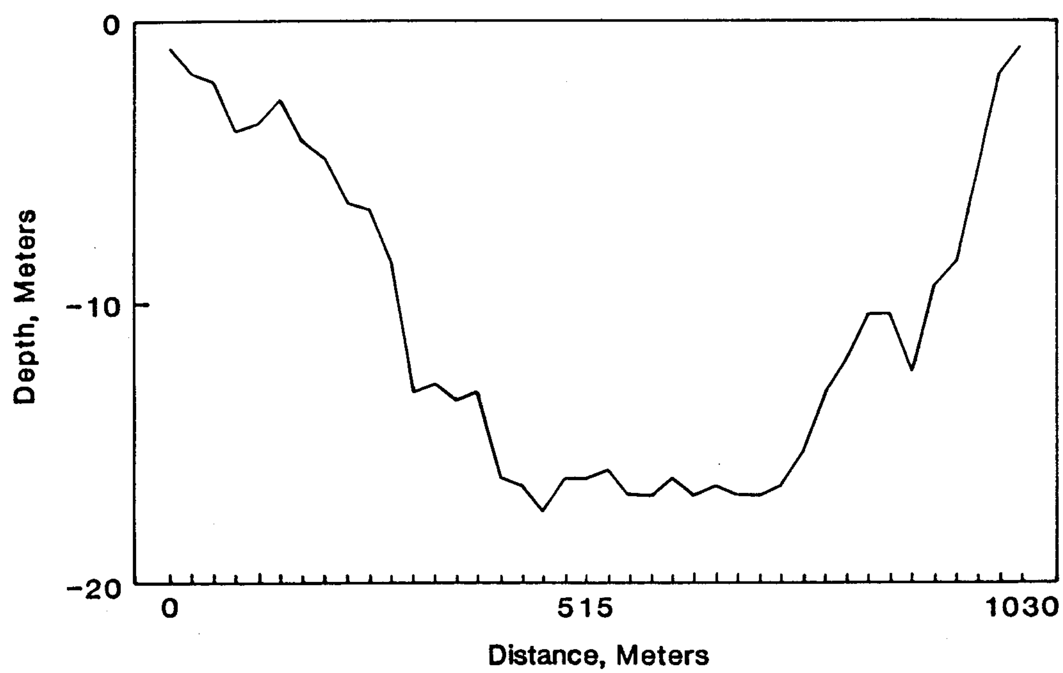
APPENDIX M

KUPARUK DEADARM "RESERVOIR 5"

DEPTH PROFILE, EAST WEST

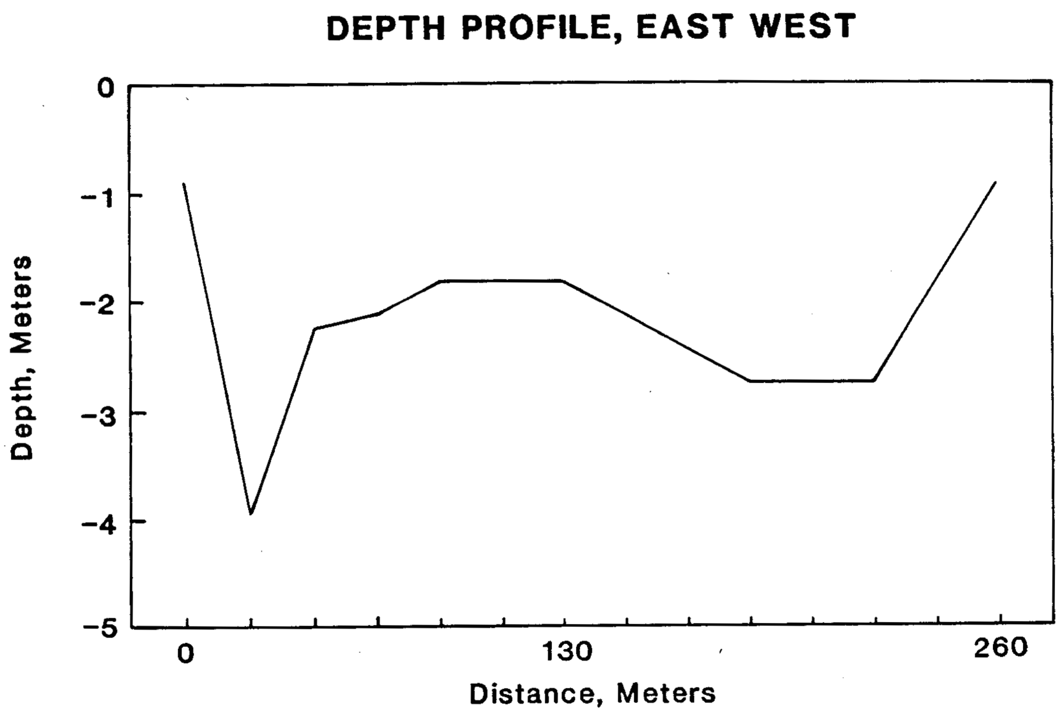


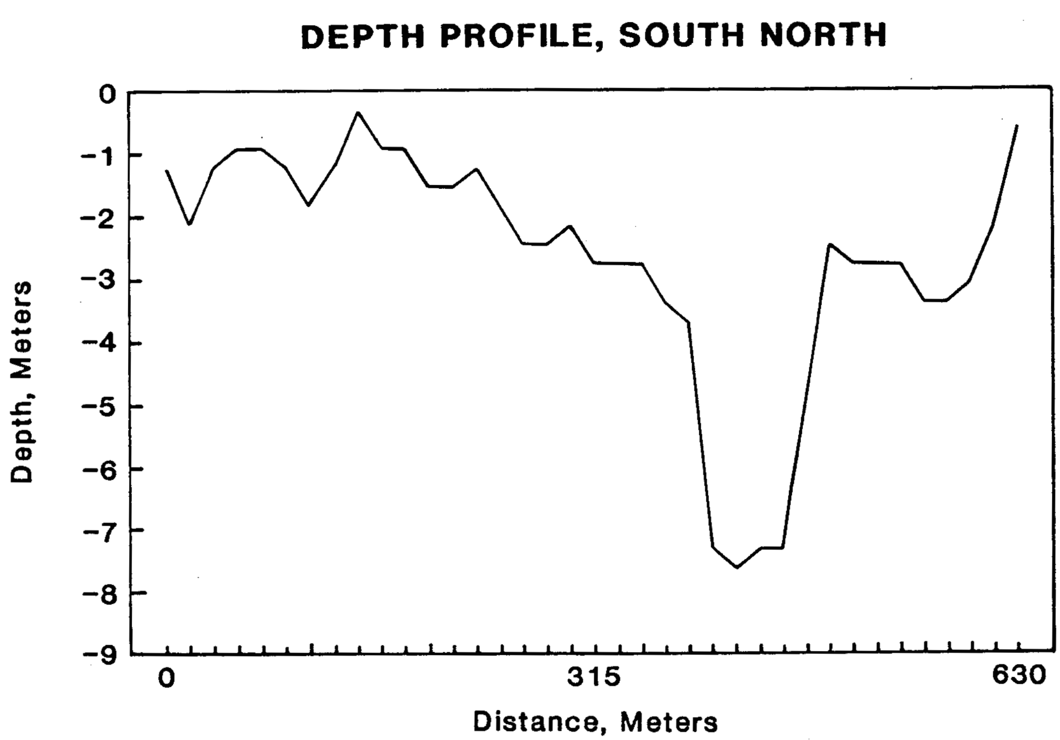
DEPTH PROFILE, NORTH SOUTH



APPENDIX M

KUPARUK DEADARM "RESERVOIR 6"





APPENDIX N

Water quality characteristics of Sag Site C during 1986 and 1987, Mid-Beaufort Region, Alaska

Sample Date	Depth (m)	Temp (°C)	Dissolved Oxygen (mg/L)	pH	Conductivity (umho/cm)	Alkalinity (mg/L)*	Hardness (mg/L)*
August 20, 1986	surface	7.5	13.4	7.9	152	69	79
	3	8.6	8.8	8.0	153	72	77
	6	8.6	11.1	7.9	153	75	77
	9	8.6	11.1	7.9	153	74	78
	12	8.6	9.1	7.9	153	75	80
	15	8.6	9.9	7.9	153	70	81
	18	8.6	9.7	7.8	158	80	84
	21	7.5	9.0	7.8	164	102	118
- Secchi Disk reading = 1.4 m							
January 7, 1987	below ice	0.5	14.7	7.2	132	90	105
	3	0.2	13.6	7.4	99	90	81
	6	0.7	12.5	7.4	97	80	83
	9	1.2	11.2	7.5	98	74	80
	12	0.8	10.3	7.3	102	74	82
	15	1.2	11.6	7.0	98	74	82
	18	1.2	11.7	7.6	94	80	83

APPENDIX N (continued)

Sample Date	Depth (m)	Temp (°C)	Dissolved Oxygen (mg/L)	pH	Conductivity (umho/cm)	Alkalinity (mg/L)*	Hardness (mg/L)*
February 27, 1987	below ice	0.9	9.3	7.8	104	104	95
	3	0.8	9.9	7.9	102	103	93
	6	1.0	9.5	7.7	101	100	89
	9	1.0	9.6	7.8	100	96	89
	12	0.8	9.4	7.8	100	98	90
	15	0.8	9.4	7.8	100	98	89
	18	0.8	9.0	7.9	100	98	90
April 25, 1987	below ice	0.9	10.5	7.7	105	90	100
	3	0.9	11.8	7.7	105	85	99
	6	0.8	11.8	7.7	100	85	94
	9	1.0	11.5	7.6	105	88	100
	12	1.0	11.3	7.7	105	83	97
	15	0.9	11.4	7.7	105	85	100
	18	0.9	11.2	7.6	105	83	100
July 14, 1987	- Secchi Disk reading = 0.8 m - Temperature profile isothermal at 4°C						
August 10, 1987	- Temperature profile isothermal at 8°C						

* Alkalinity and hardness expressed as $CaCO_3$

APPENDIX O

Water quality characteristics of Kuparuk Mine Site B during 1986 and 1987, Mid-Beaufort Region, Alaska

Sample Date	Depth (m)	Temp (°C)	Dissolved Oxygen (mg/L)	pH	Conductivity (umho/cm)	Alkalinity (mg/L)*	Hardness (mg/L)*
August 20, 1986	surface	10.5	10.9	7.5	190	41	48
	3	10.7	10.4	7.6	180	46	48
	6	10.5	11.0	7.5	165	42	43
	9	10.4	11.6	7.6	115	43	48
	10.4	10.4	10.5	7.6	114	42	49
- Secchi Disk reading = 2.3 m							
April 30, 1987	below ice	0.0	11.8	7.3	153	71	80
	3	0.0	11.9	7.4	115	79	82
	6	1.0	12.0	7.3	111	70	81
	7.6	0.5	9.0	7.2	94	75	85
July 16, 1987	surface	12					
	1.5	11					
	3	9					
	3.8	6					
	6	6					
	9	6					
August 13, 1987 - Temperature profile isothermal at 10°C							

* Alkalinity and hardness expressed as $CaCO_3$

APPENDIX P

Water quality characteristics of Kuparuk Mine Site D during 1986 and 1987, Mid-Beaufort Region, Alaska

Sample Date	Depth (m)	Temp (°C)	Dissolved Oxygen (mg/L)	pH	Conductivity (umho/cm)	Alkalinity (mg/L)*	Hardness (mg/L)*
August 20, 1986	surface	9.5	14.0	7.8	410	79	150
	3	9.3	10.8	7.8	410	78	141
	6	9.3	10.9	7.8	405	75	143
	9	9.2	11.6	7.7	410	81	140
	12	9.1	11.6	7.8	405	80	148
	13	9.0	11.0	7.8	410	85	143
- Secchi Disk reading = 0.5 m							
April 29, 1987	below ice	1.5	13.1	7.4	466	119	178
	3	1.0	13.3	7.2	433	103	171
	6	0.5	11.8	7.3	432	100	172
	9	0.5	13.2	7.3	432	115	164
	12	0.5	12.8	7.3	423	102	161
	14	0.0	11.6	7.3	460	103	162

July 14, 1987 - Secchi Disk reading = 2.0 m - Temperature profile isothermal at 4°C

August 13, 1987 - Temperature profile isothermal at 9°C

* Alkalinity and hardness as $CaCO_3$