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[EXTERNAL] RE: Comments on Coastal PLain O&G DEIS references part 5

1 message

Pam A. Miller <pammillerarctic@gmail.com> Wed, Mar 13, 2019 at 11:12 PM
To: mnhayes@blm.gov, blm_ak_coastalplain_EIS@blm.gov

More references for water resources section

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Subject: Comments on Coastal PLain O&G DEIS

Please find my comments

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5 attachments

- **of77-0492 Childers et al 1977.pdf**
  4367K
- **USFWS 1987 plate-1 DOI Final LEIS 1002 Report.pdf**
  5552K
- **WilsonEtal 1977 FWS-OBS-77-06 MapWinterWaterSourcesWinterHabitatFishWildlife.pdf**
  2979K
- **Wiswar 1994 t_1994_27 Fishes 1002 lakes tundra streams SadlerochitRivDrainage.pdf**
  1599K

Woodward et al 1988 ArchEnvironContamToxicol17 p683-697.PDF
1216K

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

HYDROLOGIC RECONNAISSANCE
OF THE
EASTERN NORTH SLOPE, ALASKA, 1975

By

Joseph M. Childers, Charles E. Sloan,
James P. Meckel, and Jon W. Nauman

OPEN-FILE REPORT 77-492

Anchorage, Alaska
1977

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ENGLISH-METRIC EQUIVALENTS

Multiply English units	By	To obtain metric units
inches (in)	25.4	millimeters (mm)
feet (ft)	0.3048	meters (m)
square feet (ft^2)	.092990	square meters (m^2)
miles (mi)	1.609	kilometers (km)
square miles (mi^2)	2.590	square kilometers (km^2)
cubic feet per second (ft^3/s)	.02832	cubic meters per second (m^3/s)
cubic feet per second per square mile [$(ft^3/s)/mi^2$]	.01093	cubic meters per second per square kilometer [$(m^3/s)/km^2$]

HYDROLOGIC RECONNAISSANCE OF THE EASTERN NORTH SLOPE, ALASKA, 1975

By Joseph M. Childers, Charles E. Sloan,
James P. Meckel, and Jon W. Nauman

ABSTRACT

Water resources of the eastern Alaskan Arctic Slope were studied by reconnaissance methods during April, August, and November 1975.

Estimates of bankfull and maximum evident flood-peak discharges by slope-conveyance methods were made for selected streams based on field evidence. Maximum evident flood-peak discharge rates averaged about 40 cubic feet per second per square mile or 0.4 cubic meter per second per square kilometer; the highest rate calculated was 185 cubic feet per second per square mile or 1.8 cubic meters per second per square kilometer and had no obvious relation to drainage basin physiography. Bankfull discharge generally exceeded 50-year flood estimates made using relations developed from Alaska stream-gaging records and multiple-regression analysis of drainage basin characteristics.

Eighteen springs, 12 lakes, and 26 streams were sampled for water analysis. Discharge of the springs ranged from less than 1 cubic foot per second or 0.03 cubic meter per second at Red Hill spring to almost 90 cubic feet per second or 2.5 cubic meters per second at the Saviukviayak and Kongakut delta springs. Temperature of spring flow ranged from about 0°C at the Clarence River spring to 33°C at Red Hill, a true hot spring. Springs were readily found by noting the location of resultant icings on Landsat imagery.

Streamflow ceases in all the streams during the late winter except in local zones of ground-water discharge that form icings downstream.

Ice thickness on lakes averaged nearly 3 feet or 1 meter by November and generally exceeded 6 feet or 2 meters by late winter. Lake water quality deteriorated during winter as the dissolved solids became concentrated when water in the shallow lakes froze. Water quality in the area, with few exceptions, was generally very good for the anticipated uses.

Fourteen springs and streams were sampled in order to gather seasonal information on aquatic invertebrate production. Production appeared to have been greatest during summer and in the warmer springs and in those whose water originated from bedrock. Summer benthic invertebrate production ranged from about 420 organisms per square foot (4,500 organisms per square meter) for the Ekaluakat River to 1,700 organisms per square foot (18,000 per square meter) for Sadlerochit Spring.

Sites satisfactory for stream-gaging stations were found on the

Colville, Hulahula, and Canning Rivers, and downstream from Saviukviayak spring and Sadlerochit Spring. These stations would provide data to help evaluate regional water resources.

INTRODUCTION

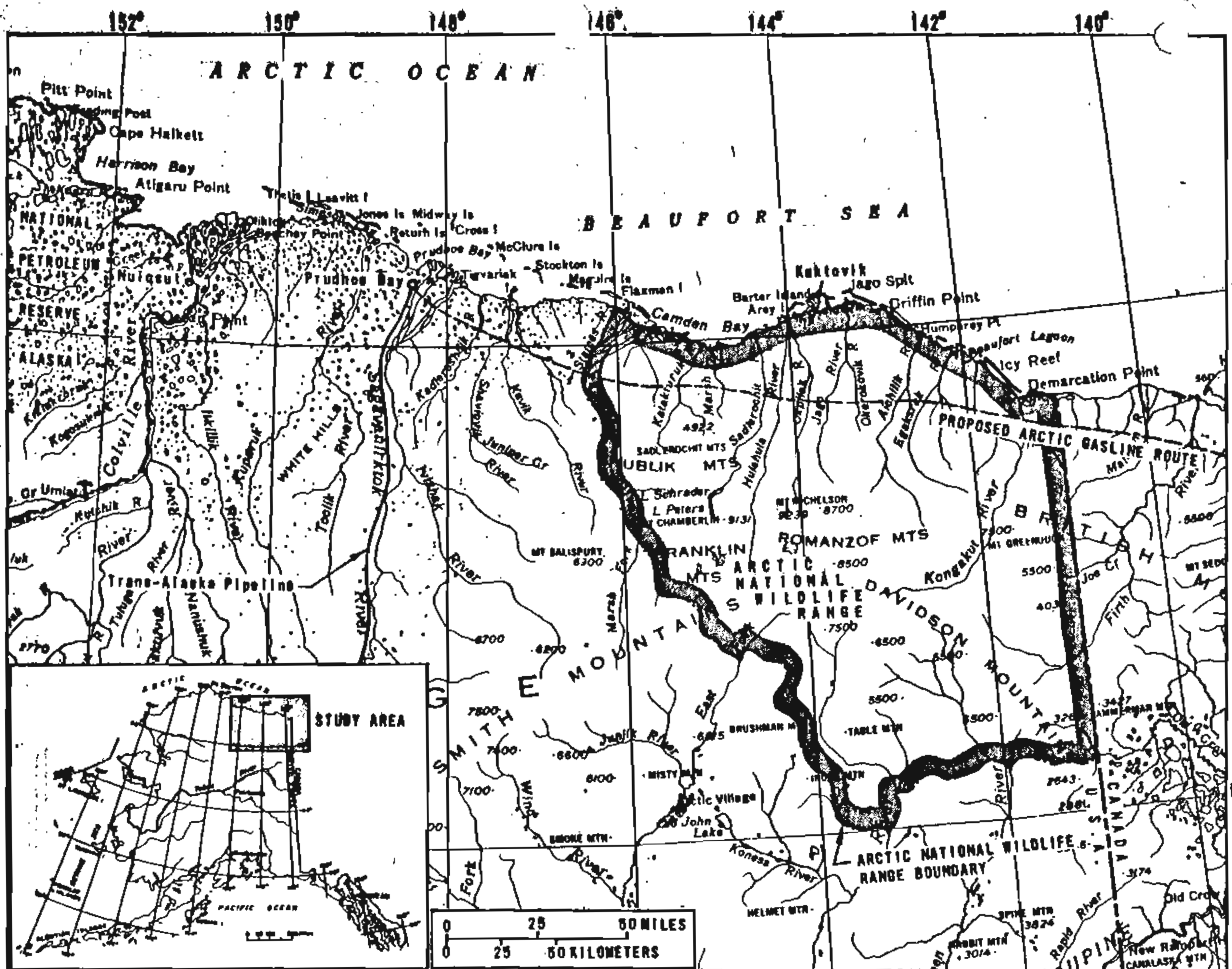
The part of the Arctic coast of Alaska between the Colville River and the Canadian boundary was visited in April, August, and November 1975. The location of the area is shown in figure 1. The proposed route of the Arctic Gas pipeline and the lower Colville River area are included in the study. The reconnaissance study area is characterized by its cold climate and is largely uninhabited, but oil and gas discoveries have spurred development of parts of the area. Sensible, coordinated development requires information about water resources, information which, until recently, has not been available.

The purpose of the April 1975 reconnaissance trip was to locate winter flow and describe its quantity and quality. A followup summer trip was made in August to determine the flood characteristics of selected streams by measuring channel geometry in relation to bankfull discharge and the maximum evident flood and by estimating channel roughness. In addition, one lake was sampled, the discharge of a few springs was measured, and samples of spring water were taken. Because streamflow in August was assumed to be representative of normal summer flow, water quality was examined in streams for which flood surveys had been made. Samples of aquatic invertebrate populations were taken from most sites on the April and August trips. Another reconnaissance trip from Prudhoe Bay east to Canada was made in November to measure discharge in selected streams and springs, to measure ice thickness and water depth in selected lakes, and to collect water samples for water-quality analyses.

FLOODS

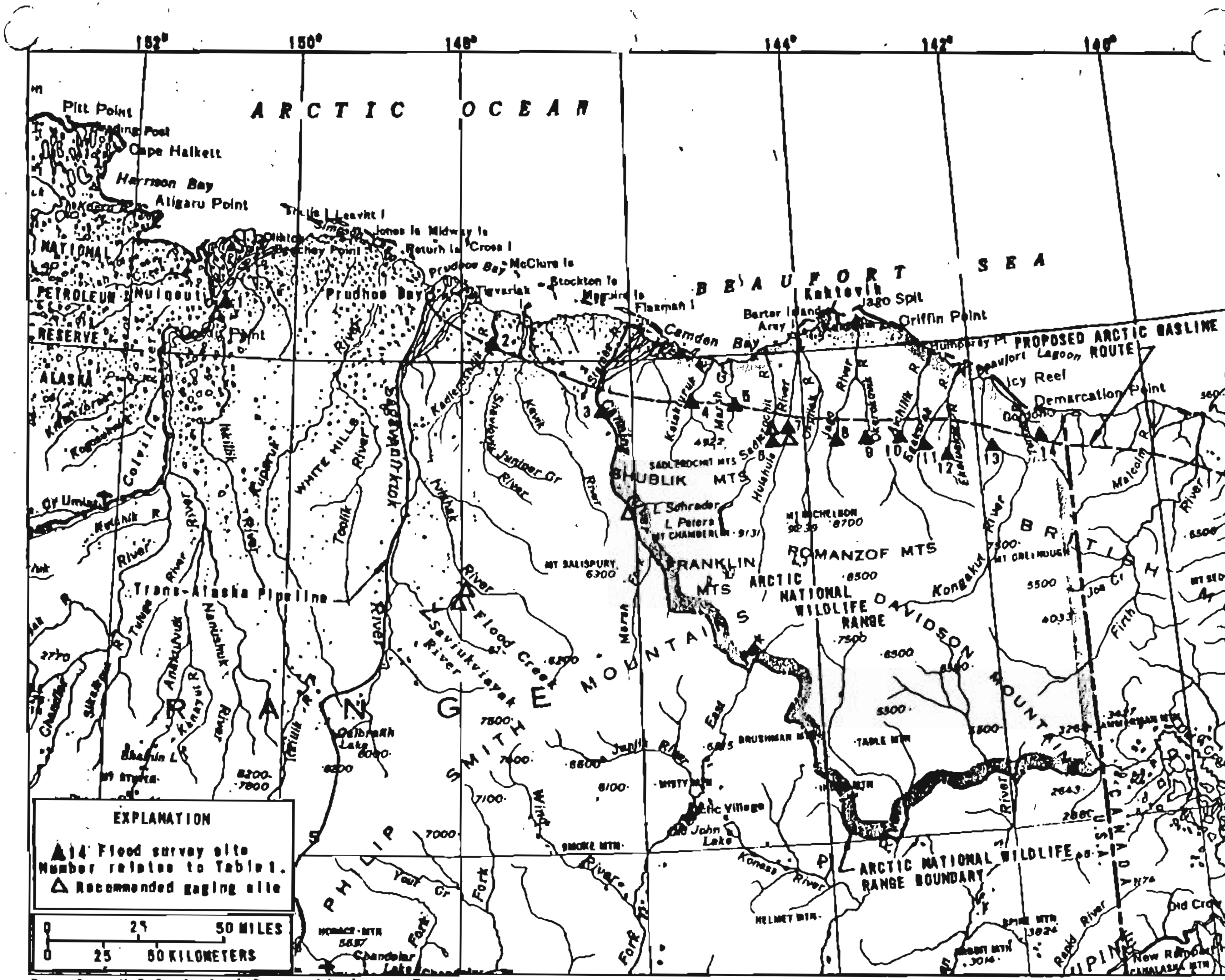
The reconnaissance party made flood surveys at 14 stream sites. These flood-survey sites are numbered on figure 2. The streams and the approximate survey sites were preselected on topographic maps and studied from the air to insure that reasonably uniform channel reaches were available for ground surveys. An oblique aerial photograph of each site was made (figs. 3-16). The party then surveyed the channel cross sections and longitudinal profiles of the water surface, the bank tops, and the maximum evident flood high-water marks upstream and downstream from the cross sections. At each site a photograph was made of an area of the streambed covered with deposits that were considered to be representative of the size of streambed material transported during floodflow conditions. The cross-section lines on the aerial photographs show the widths of the channels at bankfull and maximum evident flood stages.

The results of the stream-site studies are shown in table 1. The channel characteristics tabulated are for the bankfull main channel.



Base from U.S.Geological Survey Alaska Map E

Figure 1.--Reconnaissance study area, eastern North Slope, Alaska.



Base from U.S.Geological Survey Alaska map E

Figure 2.--Location of flood-survey sites and recommended stream-gaging sites.

Figures 3-16.-- Photographs of flood survey sites. Upper photo shows channel width in feet. Arrow indicates direction of flow. X indicates site where bed material was photographed; □ indicates site where biological sample was taken, if any. Lower photo shows typical streambed material.

FIG. 3a - Halftone @ 100%

FIG. 3b. - Halftone @ 62%

Figure 3.-- Site 1, Colville River.

$3\,3/8 \times 6\,1/2$

CROP

CROP

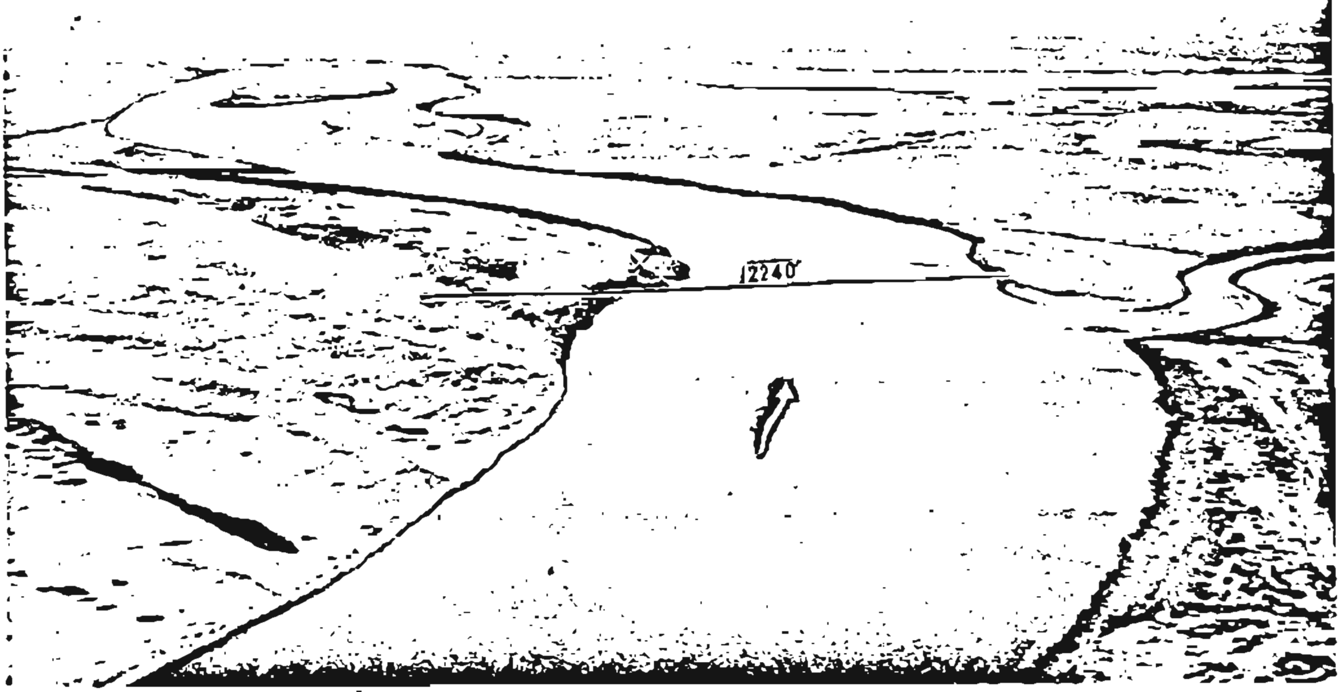


FIG. 3a - Halftone @ 100%

4" x 4 3/8"

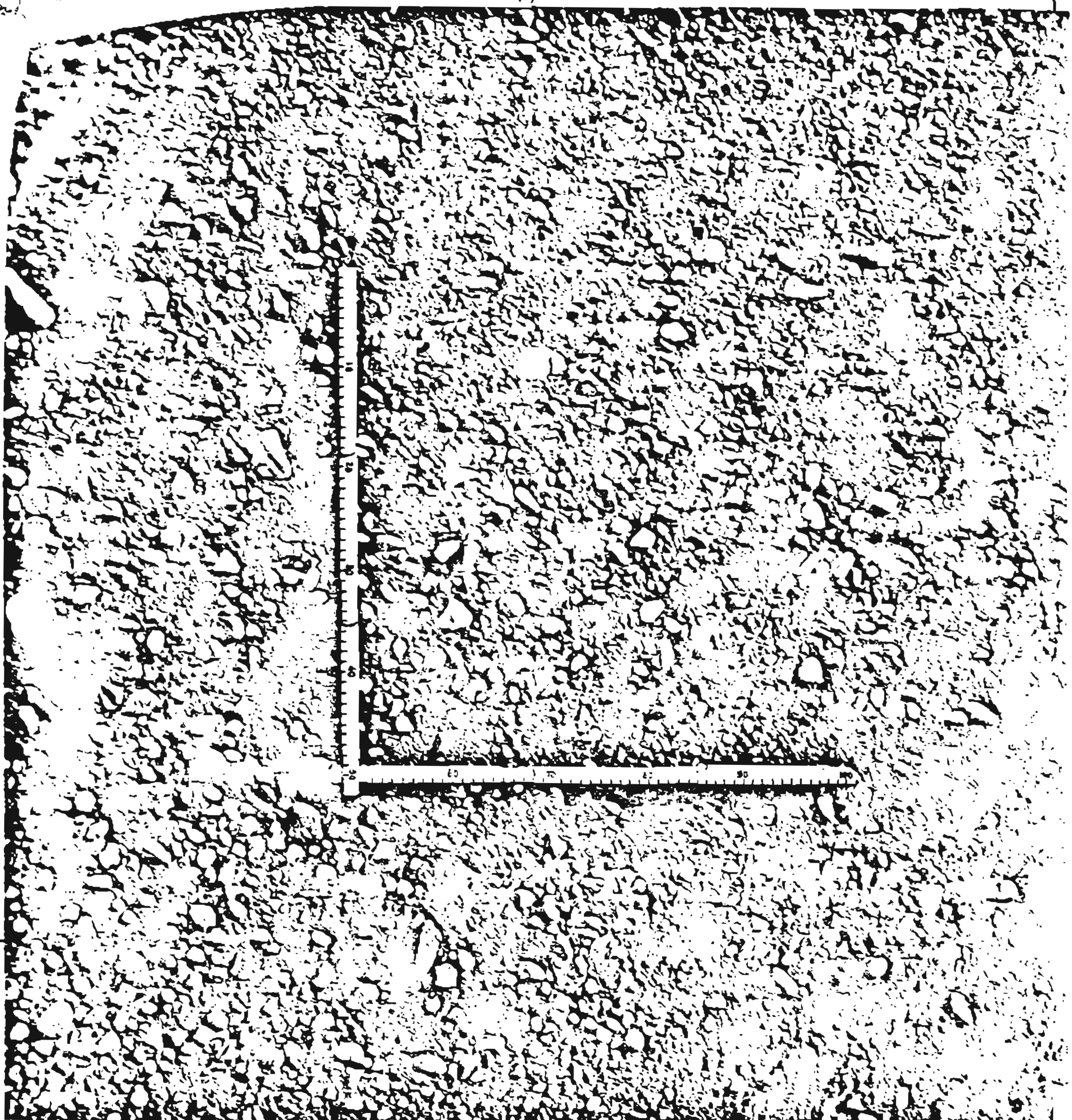


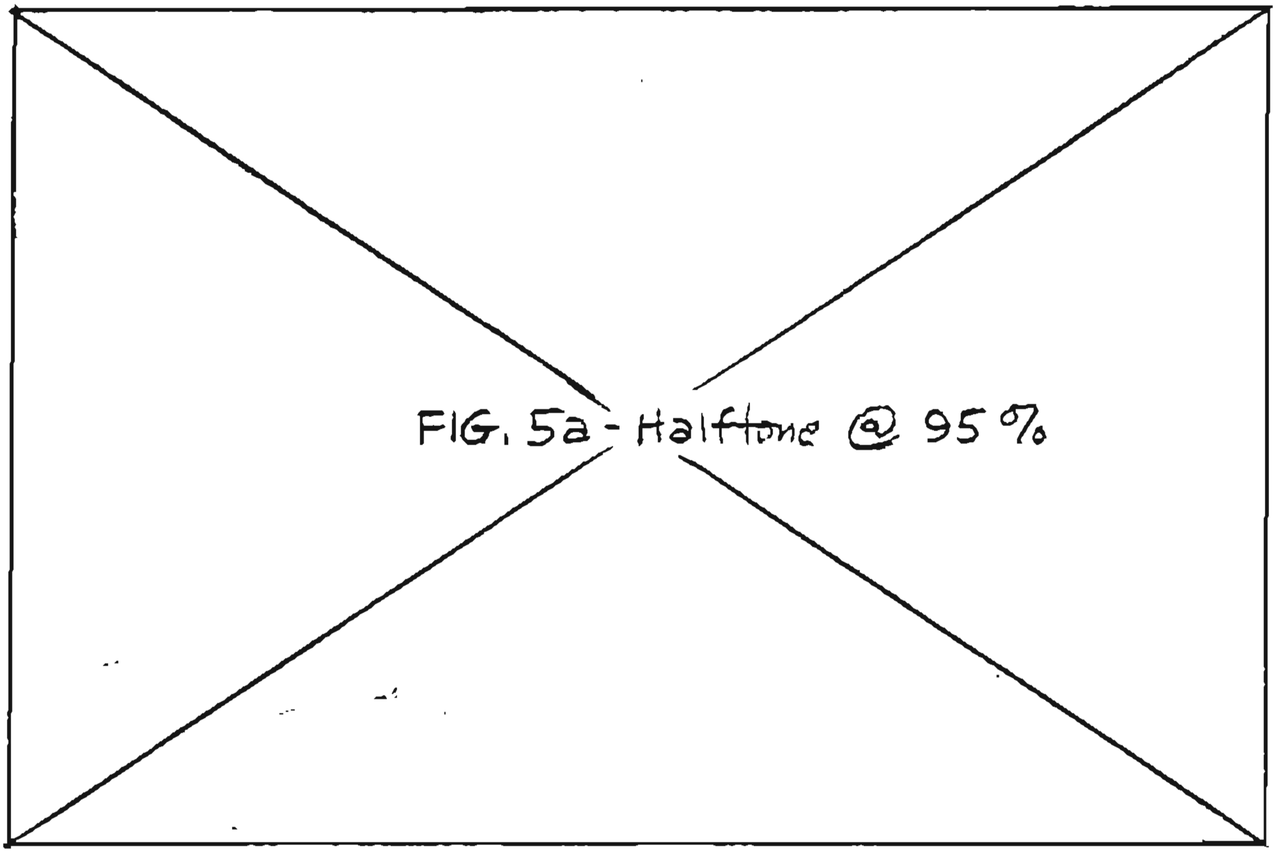
Fig. 3b - Reduce to 62% Halftone

FIG. 4a - Halftone @ 100%

FIG. 4b - Halftone @ 100%

Figure 4.-- Site 2, Shaviovik River.

FIG. 4b - 100% Halftone



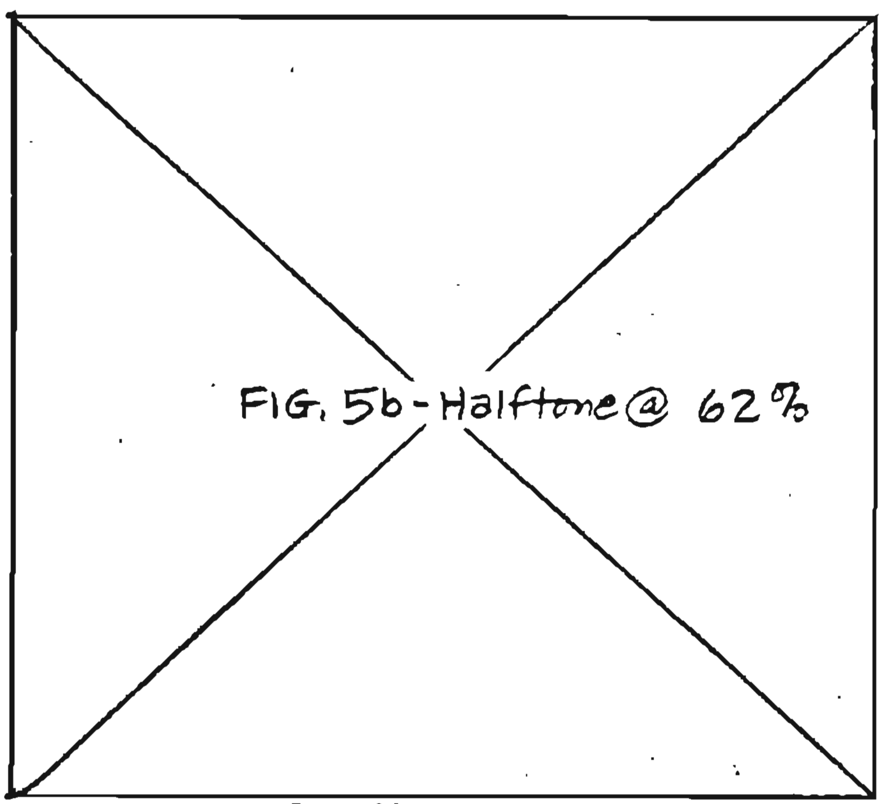


Figure 5.-- Site 3, Canning River.

TOP

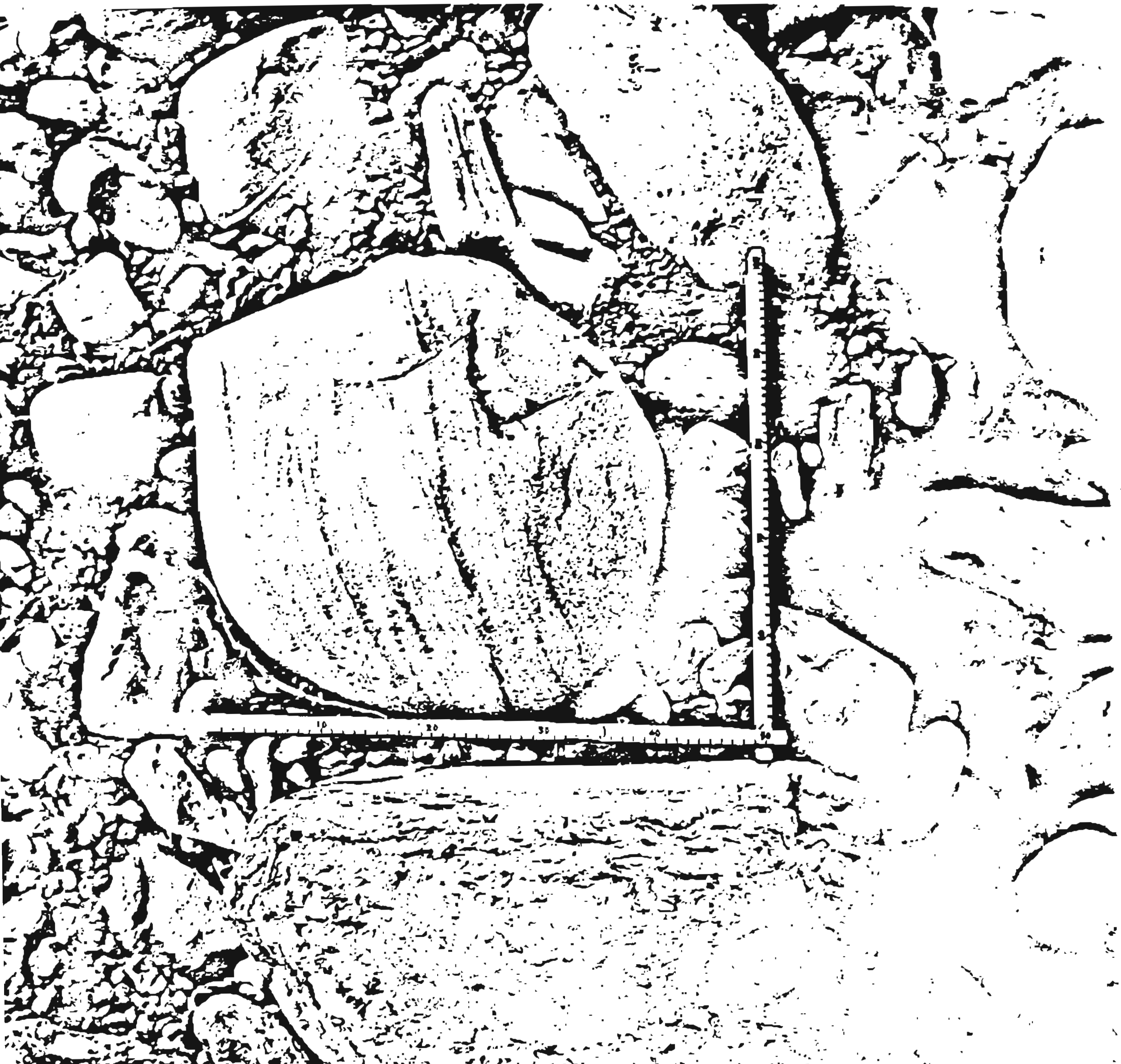


Fig 5b - Reduce to 62% Halftone

4 1/4 x 6 1/2

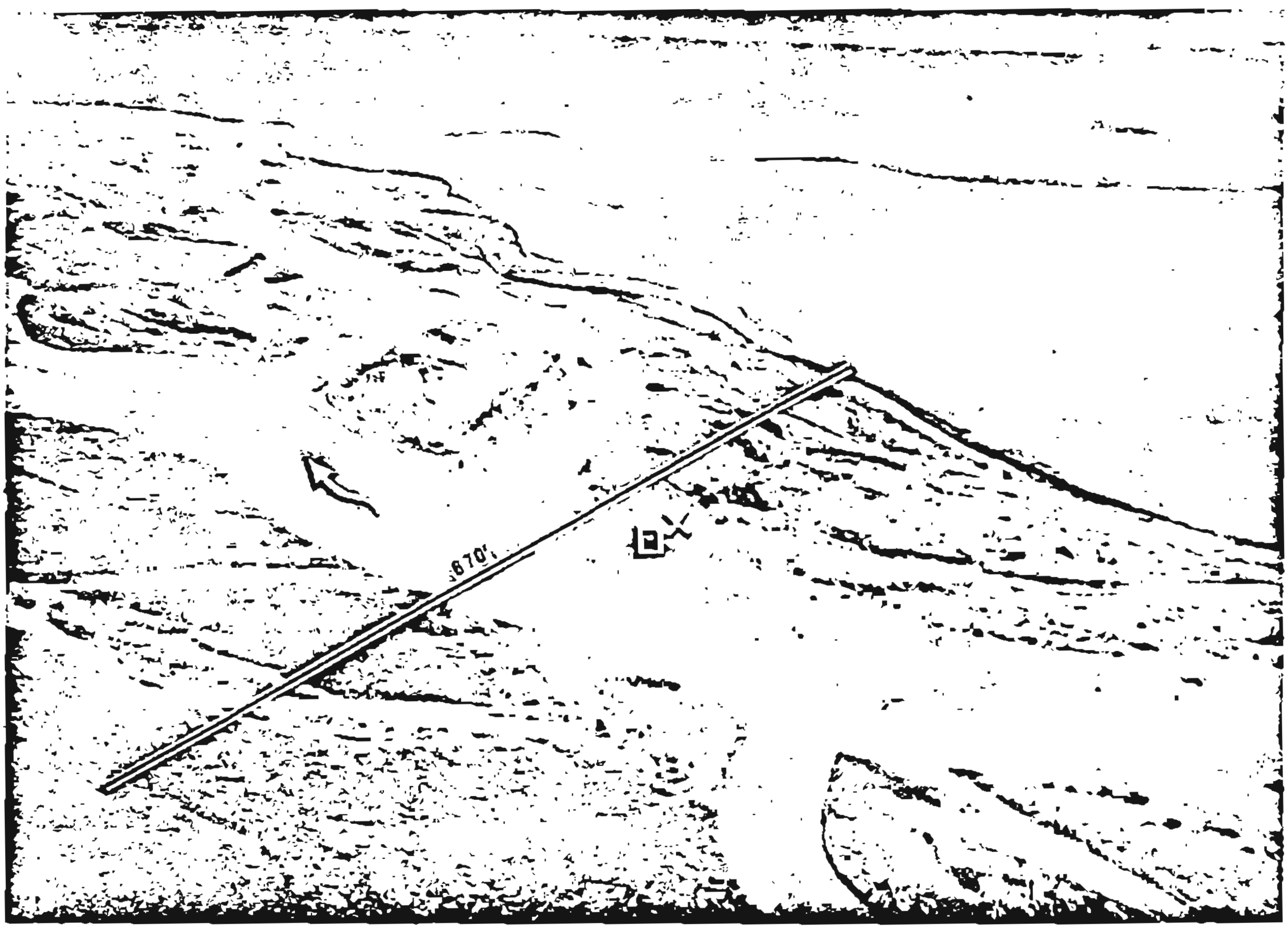


FIG. 6a - Halftone @ 100%

4X 4 3/8

TOP

Fig. 6 b - Reduce to 62% Halftone

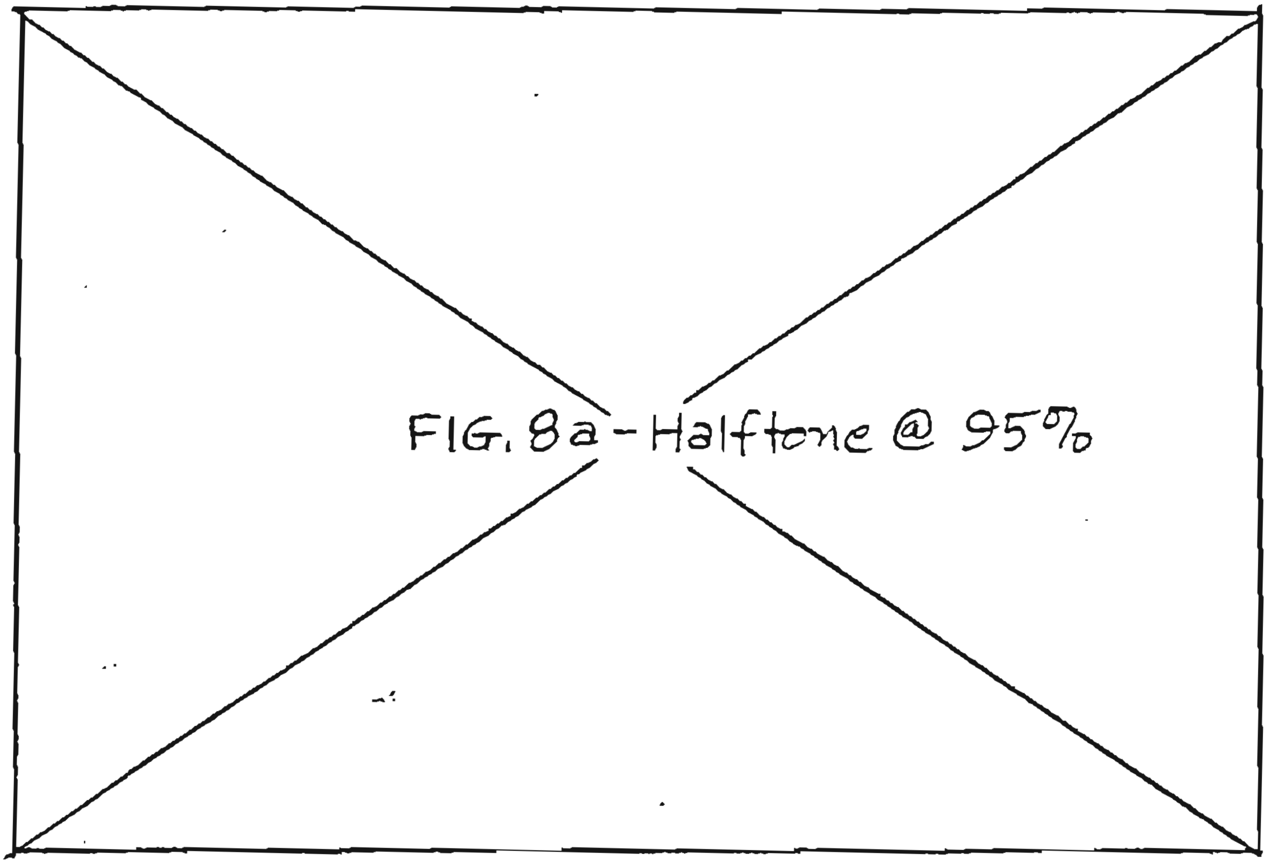
FIG. 7a - Halftone @ 100%

FIG. 7b - Halftone @ 62%

Figure 7.-- Site 5, Marsh Creek.

FIG. 7a - Halftone @ 100%

Fig. 7b - Reduce to 62% Halftone



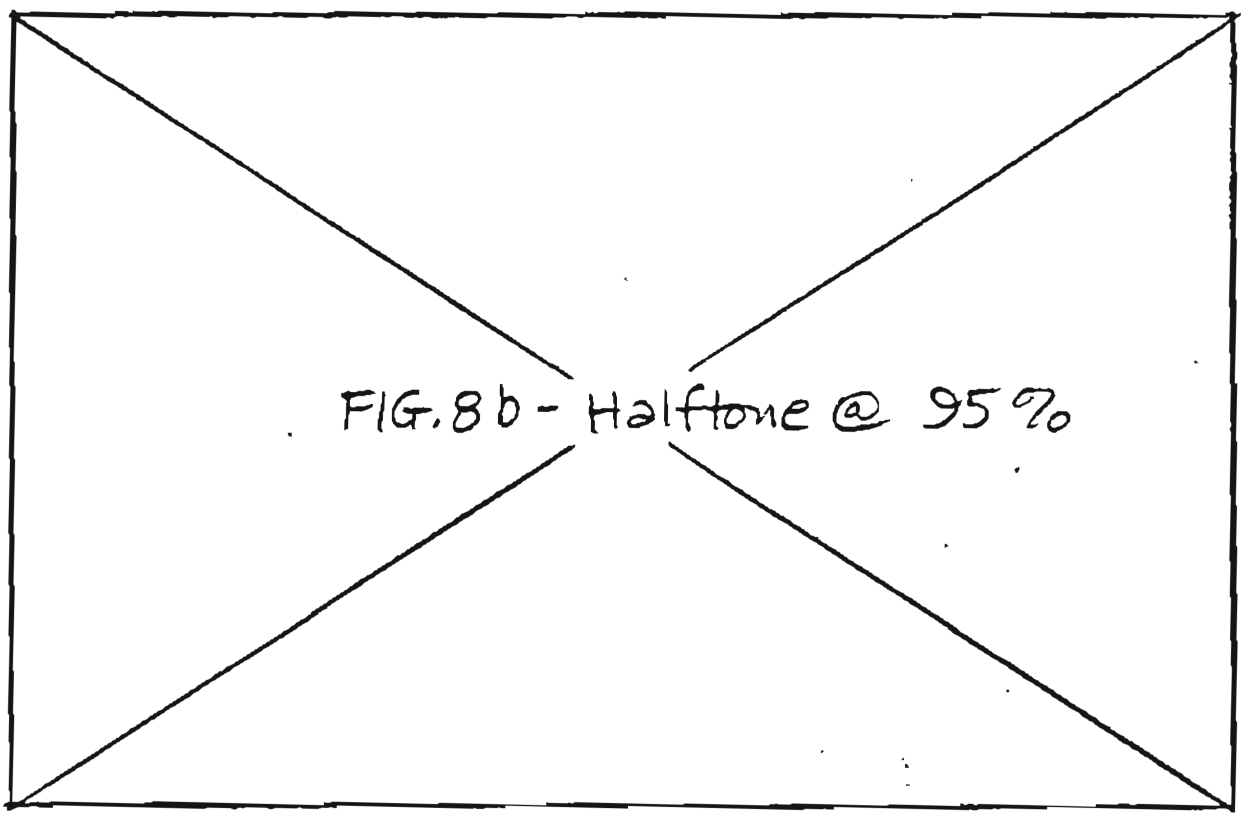


Figure 8.-- Site 6, Sadlerochit River.

Fig. 8a - Halftone @ 95%

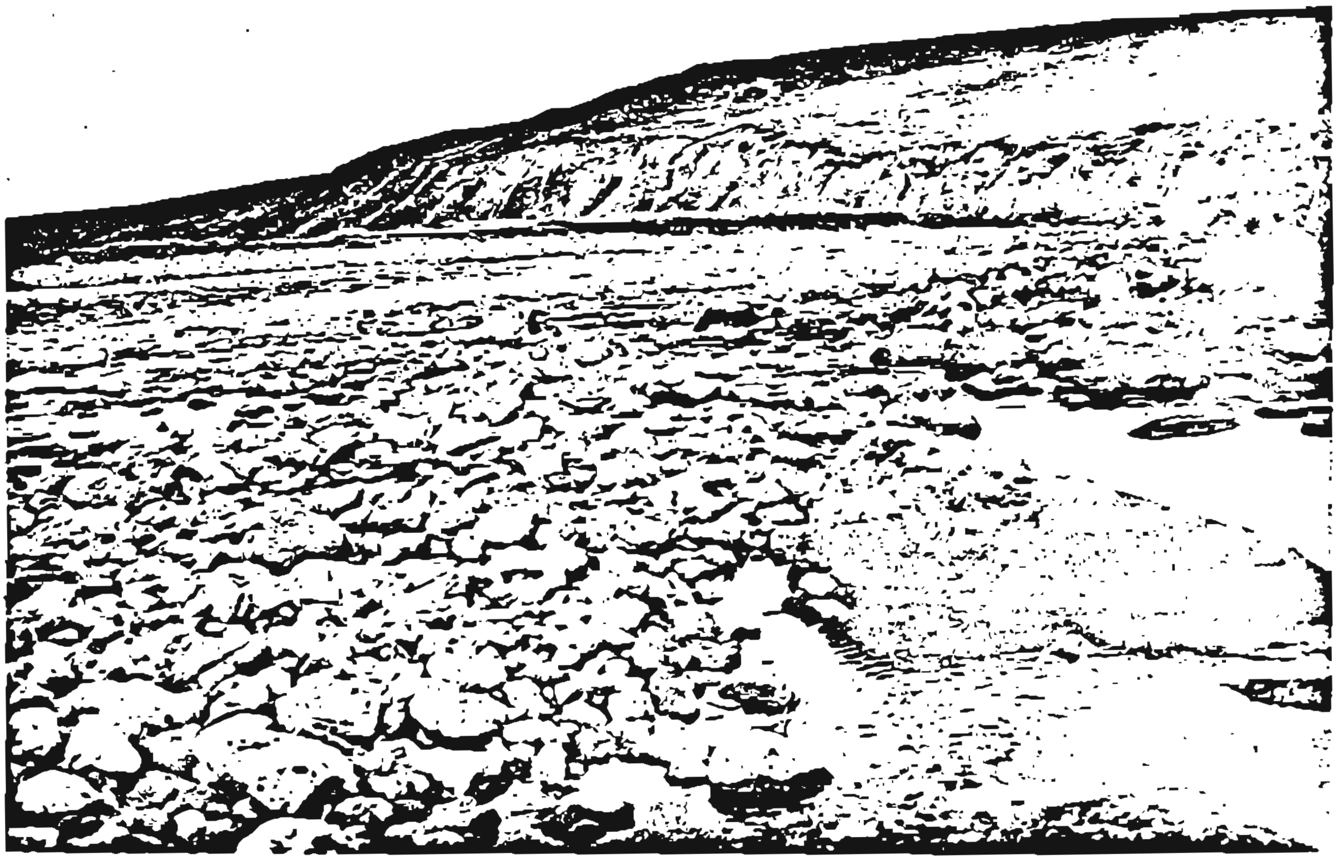


Fig. 8b - Halftone @ 95%

FIG. 9a - Halftone @ 100%

FIG. 9b - Halftone @ 62%

Figure 9.-- Site 7, Hulahula River

4¼ x 4¾

Fig. 9a - Halftone @ 100 %

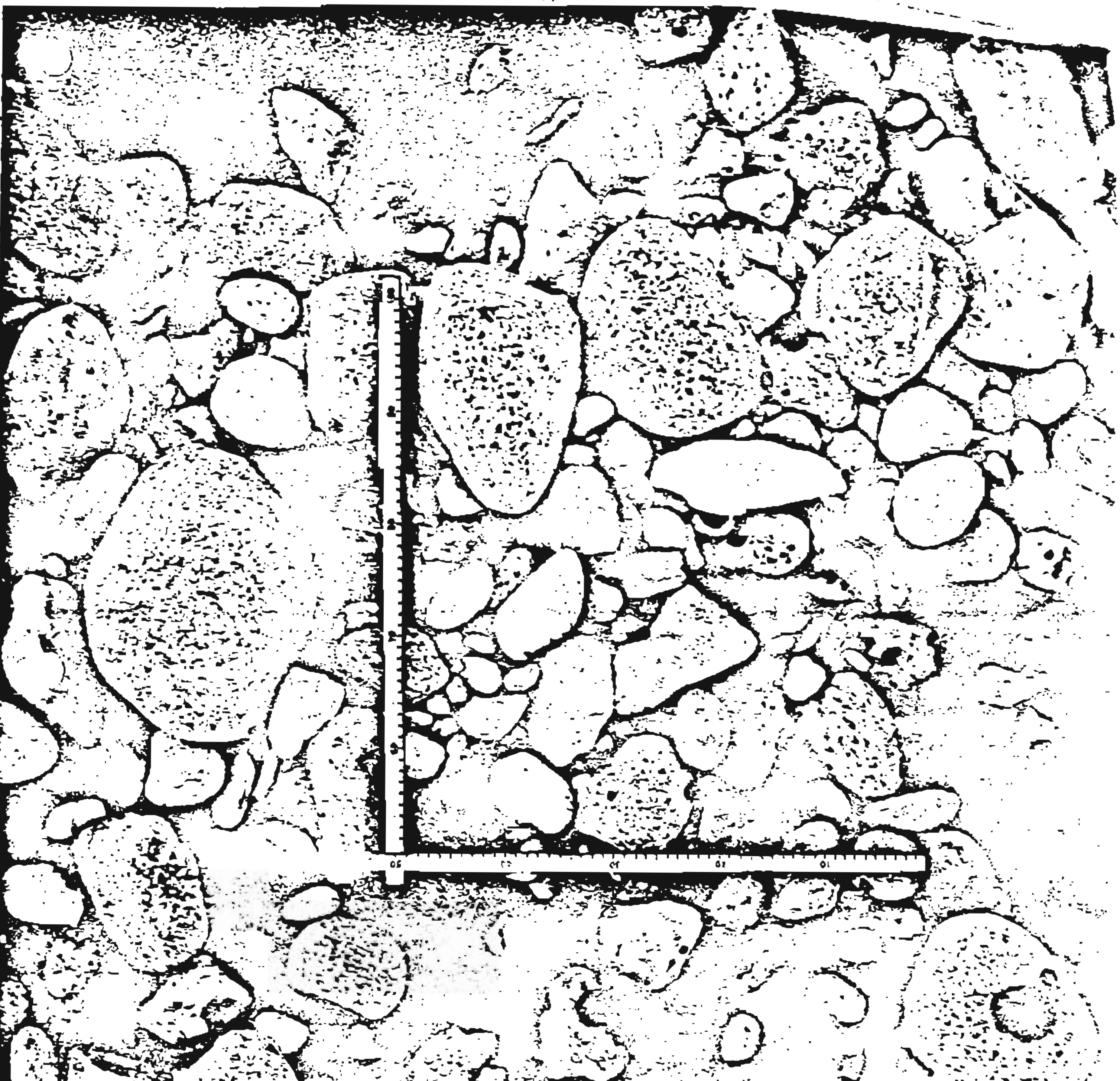
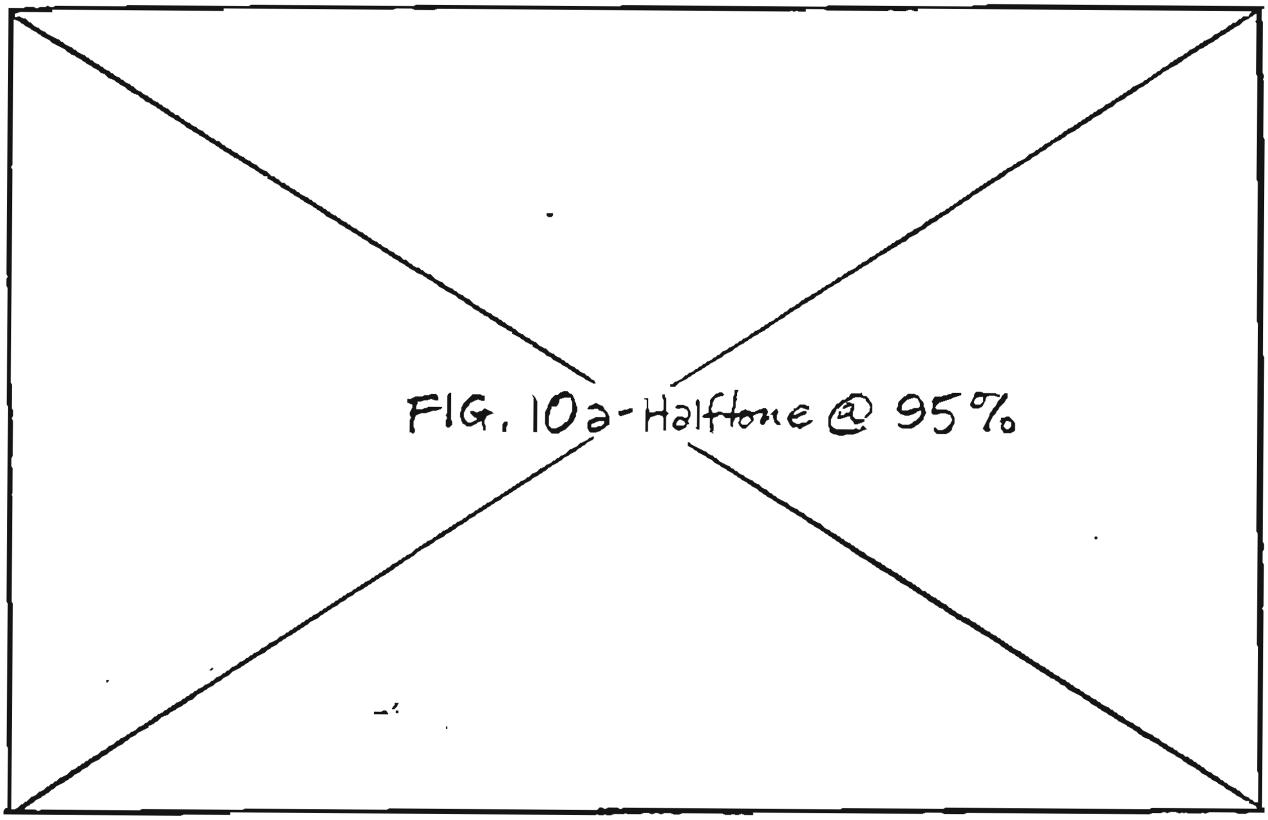


Fig. 9b -- Reduce to 62% Halftone



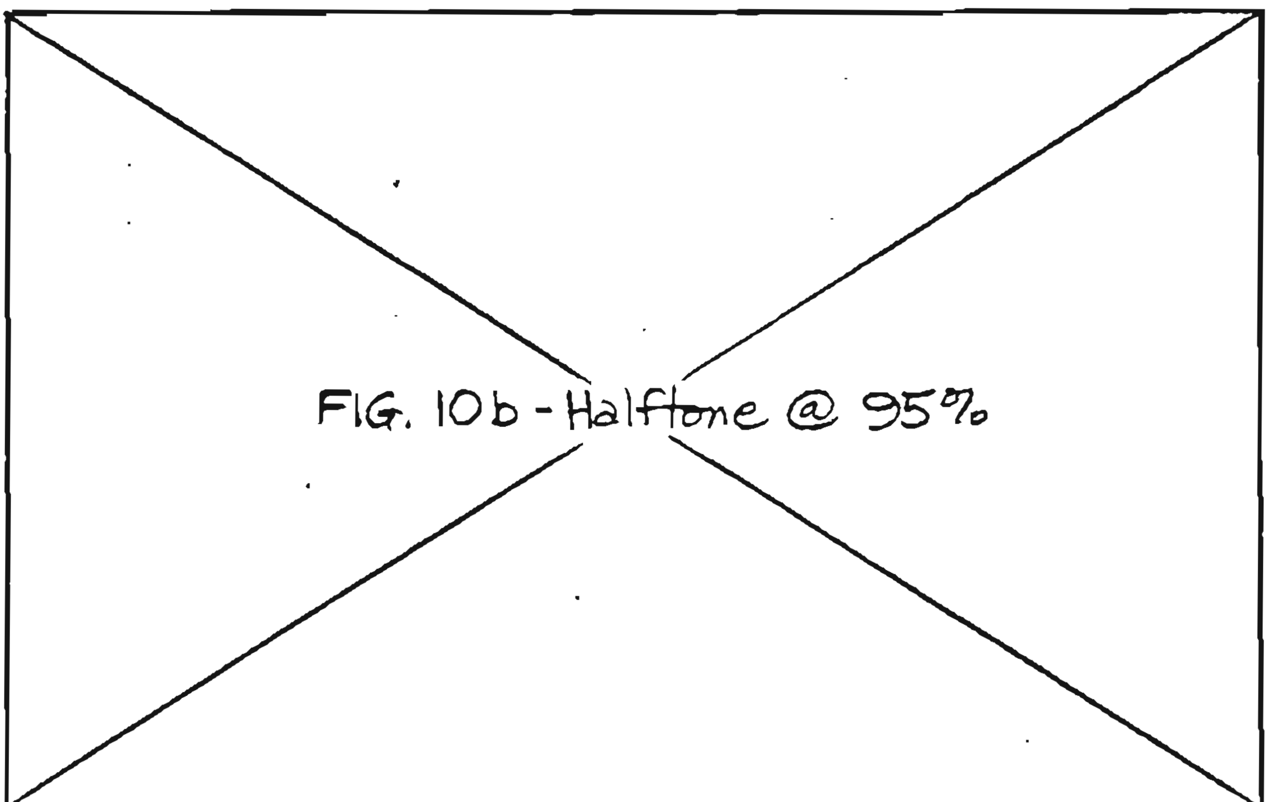


Figure 10.-- Site 8, Jago River.

4 1/16 x 6

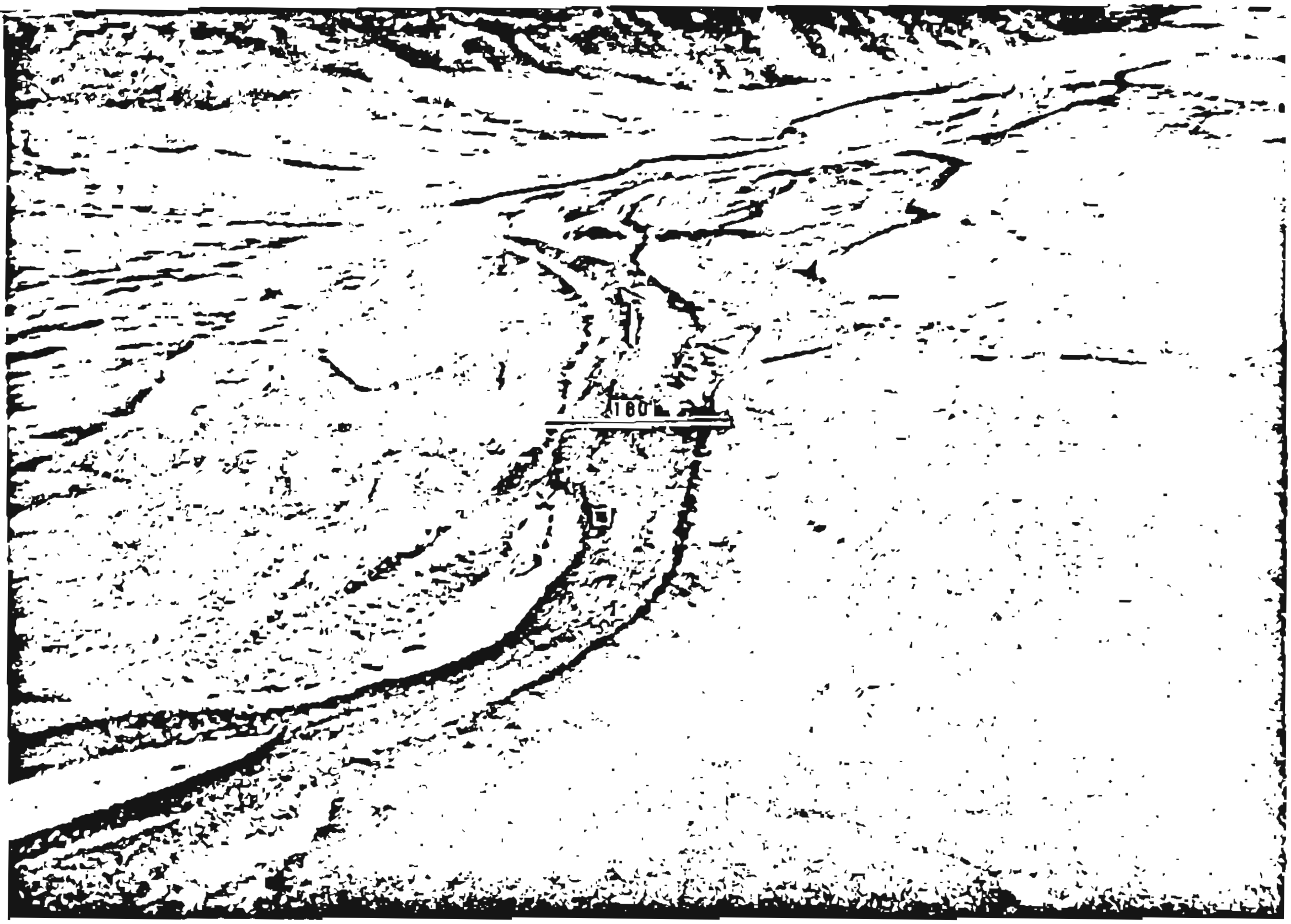
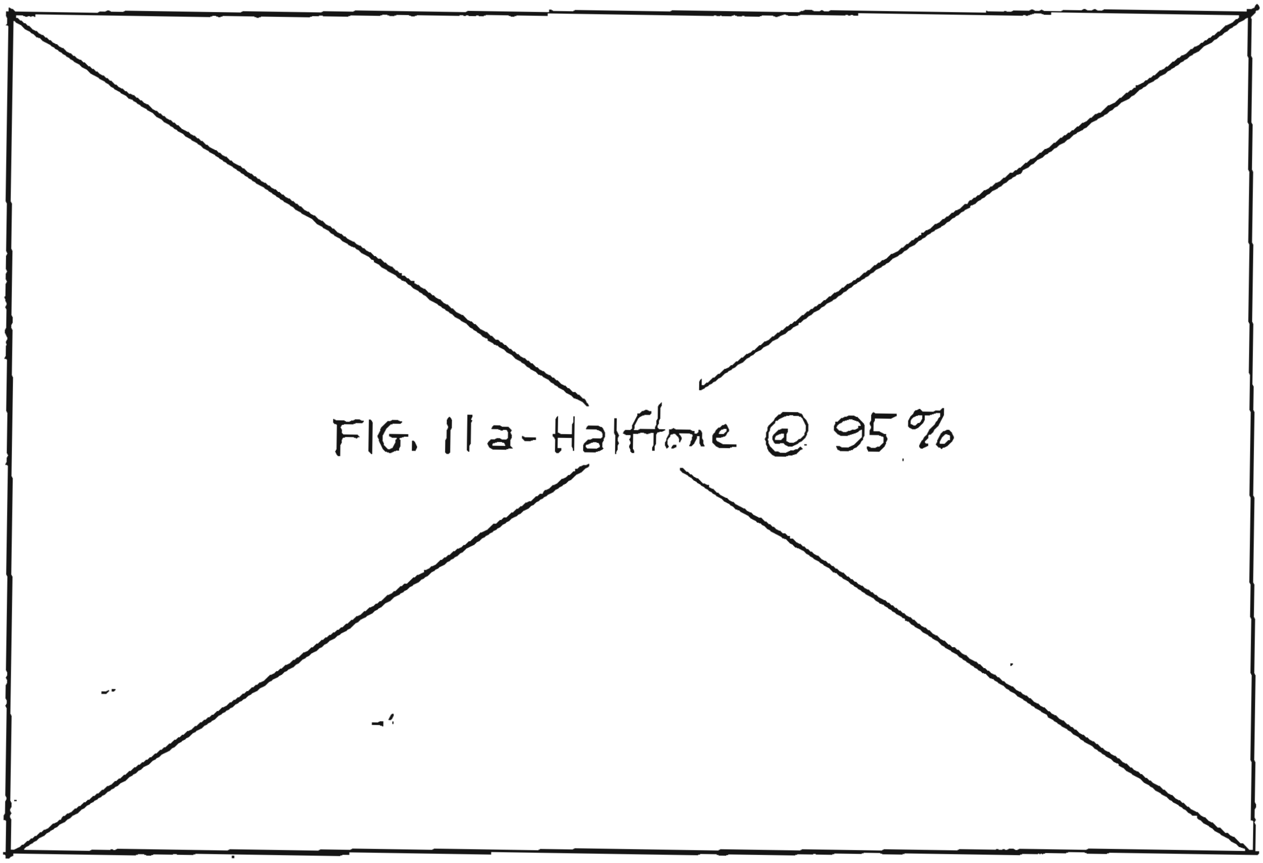


Fig. 10 a. – Halftone @ 95%

$4\frac{5}{16} \times 6\frac{3}{8}$

Fig. 10 b - Halftone @ 95%



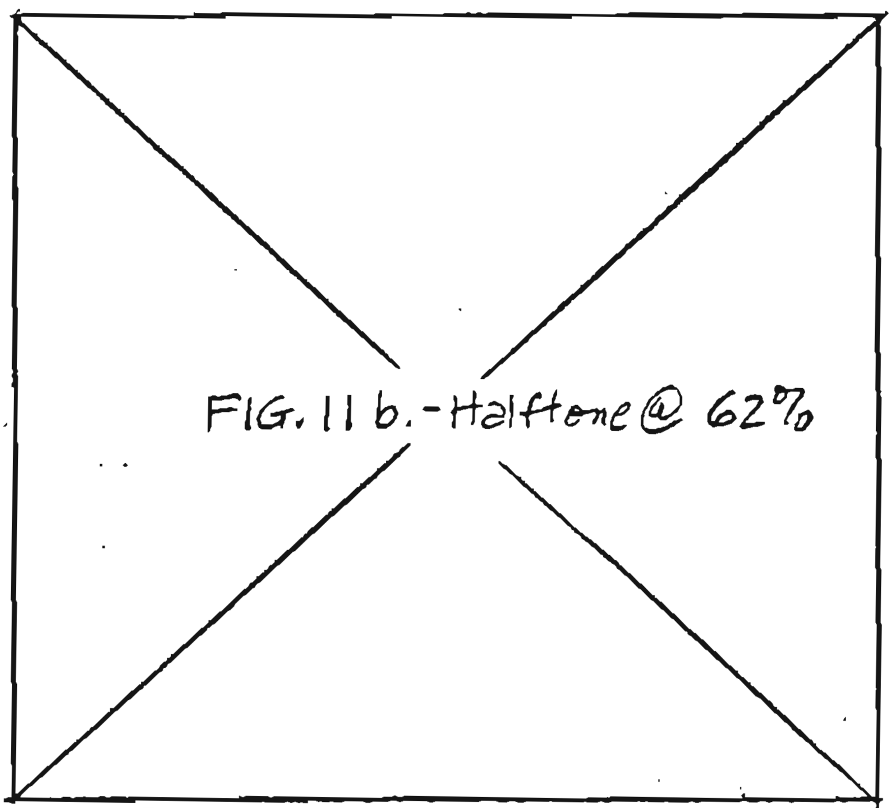


Figure 11.-- Site 9, Okerokovik River.

4 1/4 x 6 3/8

Fig. 11 a - Halftone @ 95%

4x4 3/8

Fig. 11 b - Reduce to 62% Halftone

FIG. 12a-Halftone @ 100%

FIG. 12b-Halftone @ 62%

Figure 12.-- Site 10, Aichilik River.

4¼ x 6¹¹⁄₁₆

FIG. 12a - Halftone @ 100%

4" x 4"

TOP

Fig. 12 b - Reduce to 62% Halftone

FIG. 13a - Halftone @ 100%

FIG. 13b - Halftone @ 100%

Figure 13.-- Site 11, Egaksrak River.

4 1/16 x 6 11/16

Fig. 13a - Halftone @ 100%

$3\frac{7}{8} \times 6\frac{11}{16}$

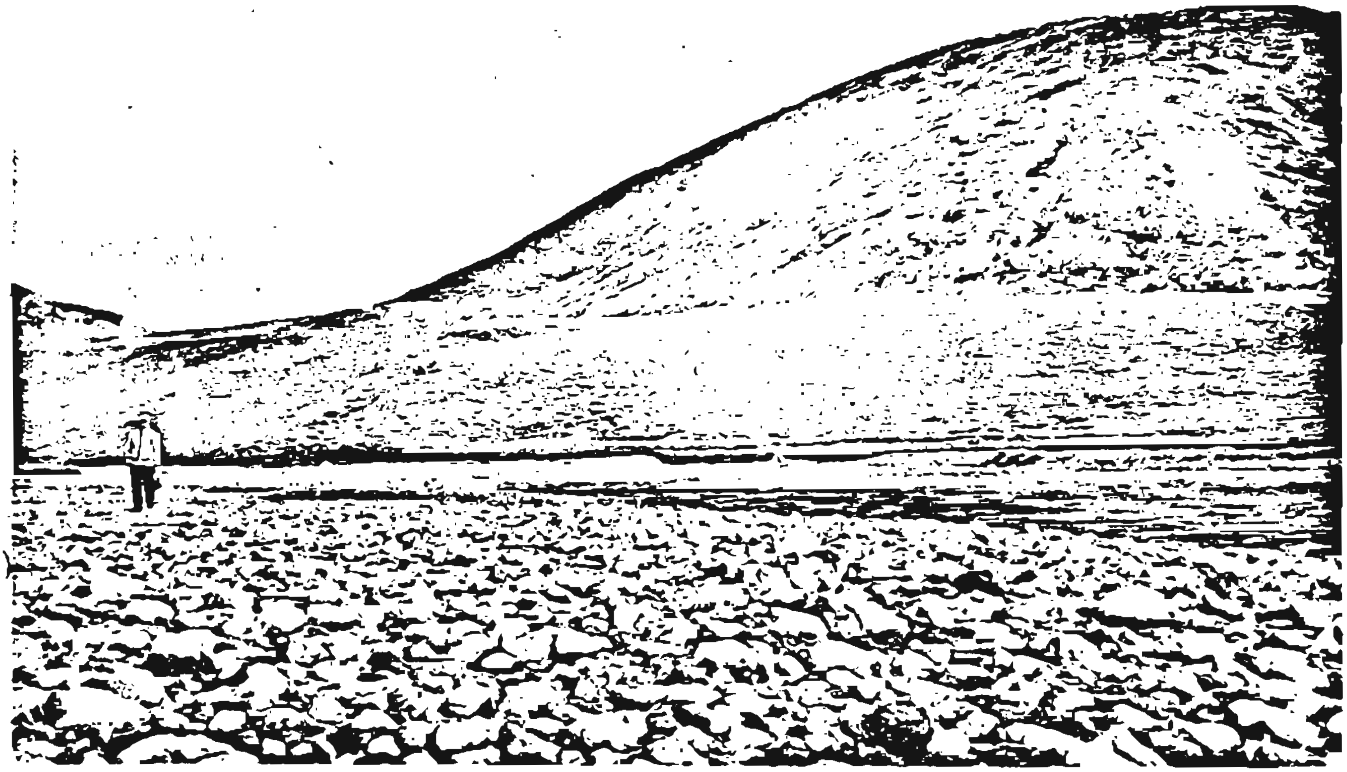


Fig. 13b - Halftone @ 100%

FIG. 14a - Halftone @ 100%

FIG. 14b. - Halftone @ 62%

Figure 14.--Site 12, Ekaluakat River.

4 1/4 x 6 1/2

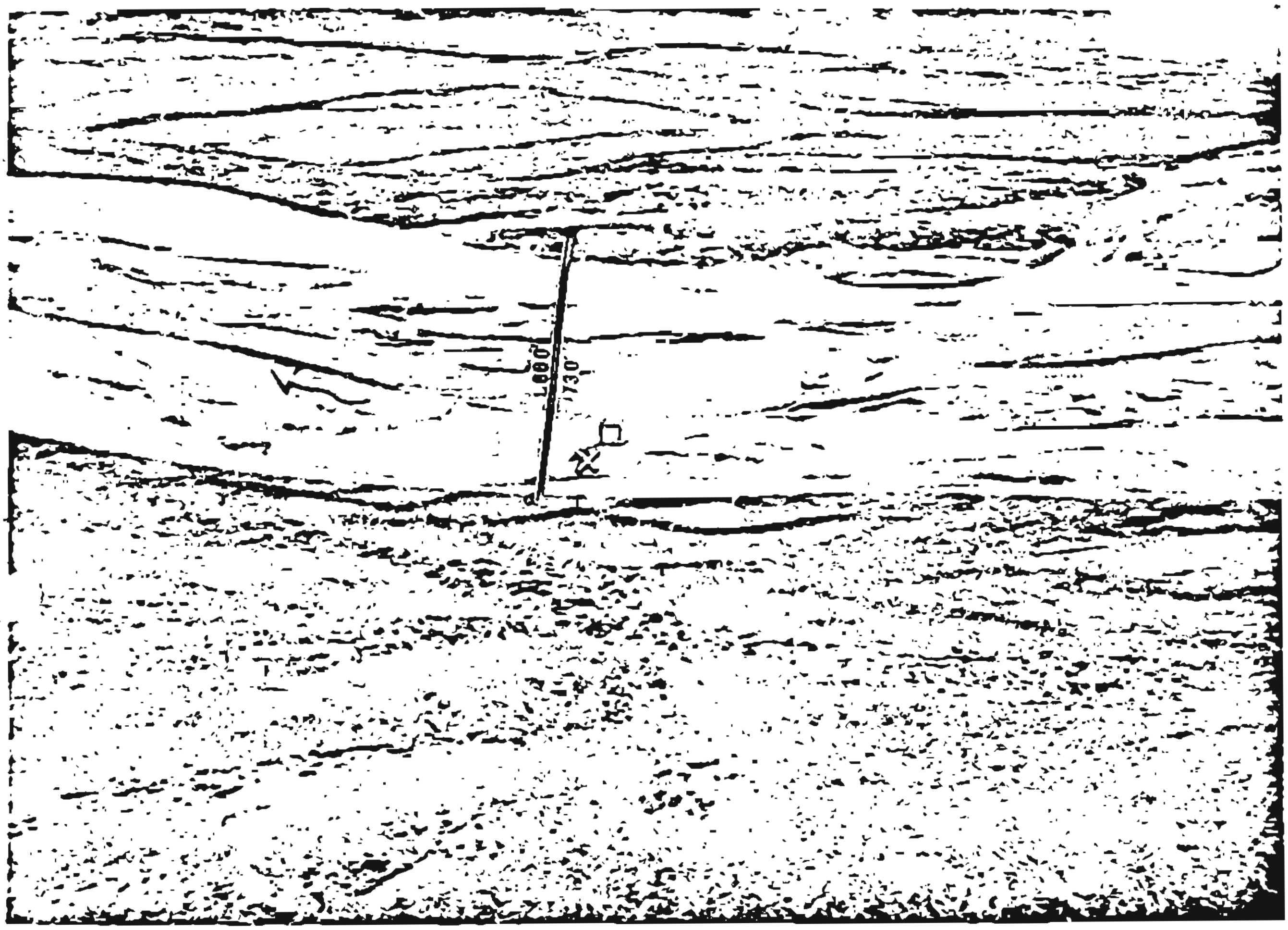


Fig. 14 a - Halftone @ 100%

Fig. 14b- Reduce to 62% Halftone

FIG. 15a-Halftone @ 95%

FIG. 15b.-Halftone @ 62%

Figure 15.-- Site 13, Kongakut River.

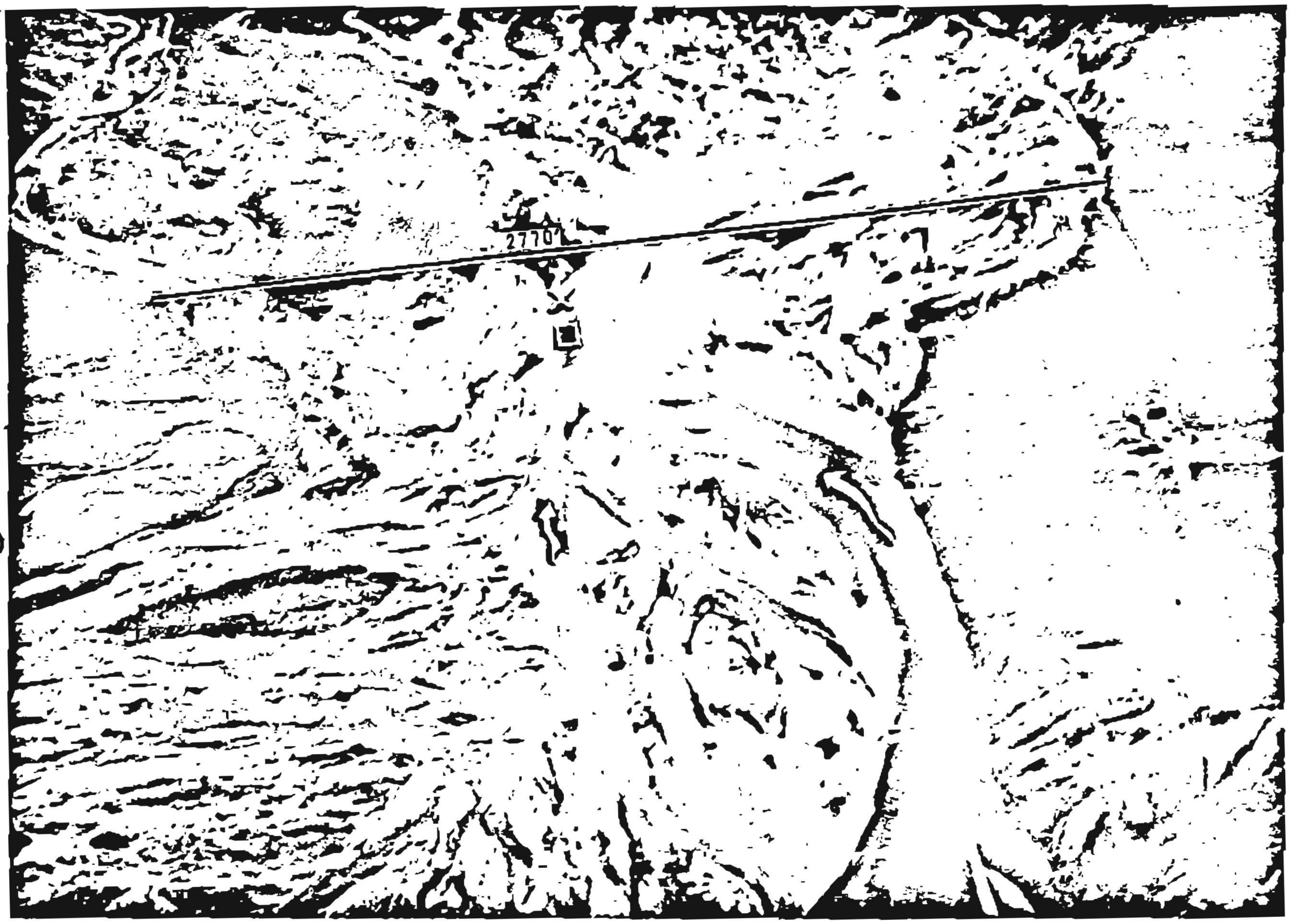
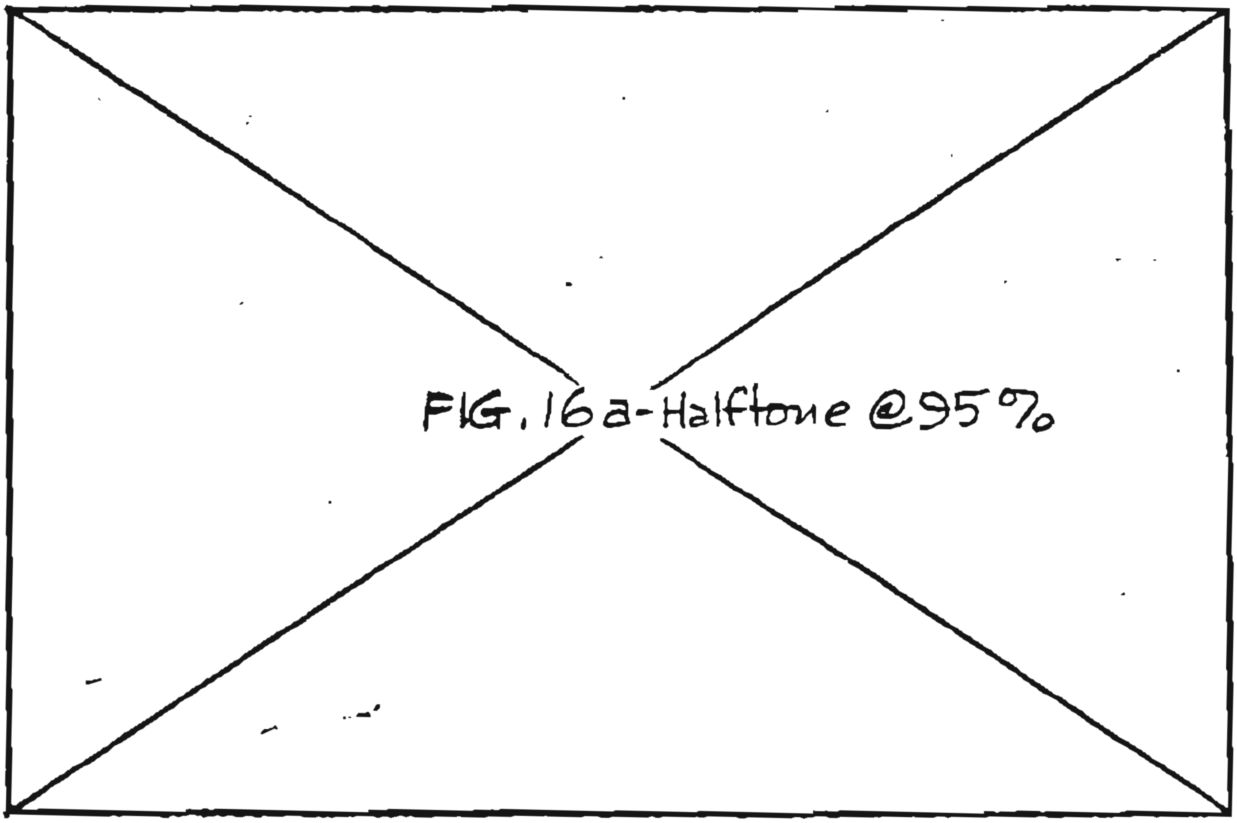


FIG. 15a - Halftone @ 95%

TOP

Fig. 15 b - Reduce to 62% Halftone



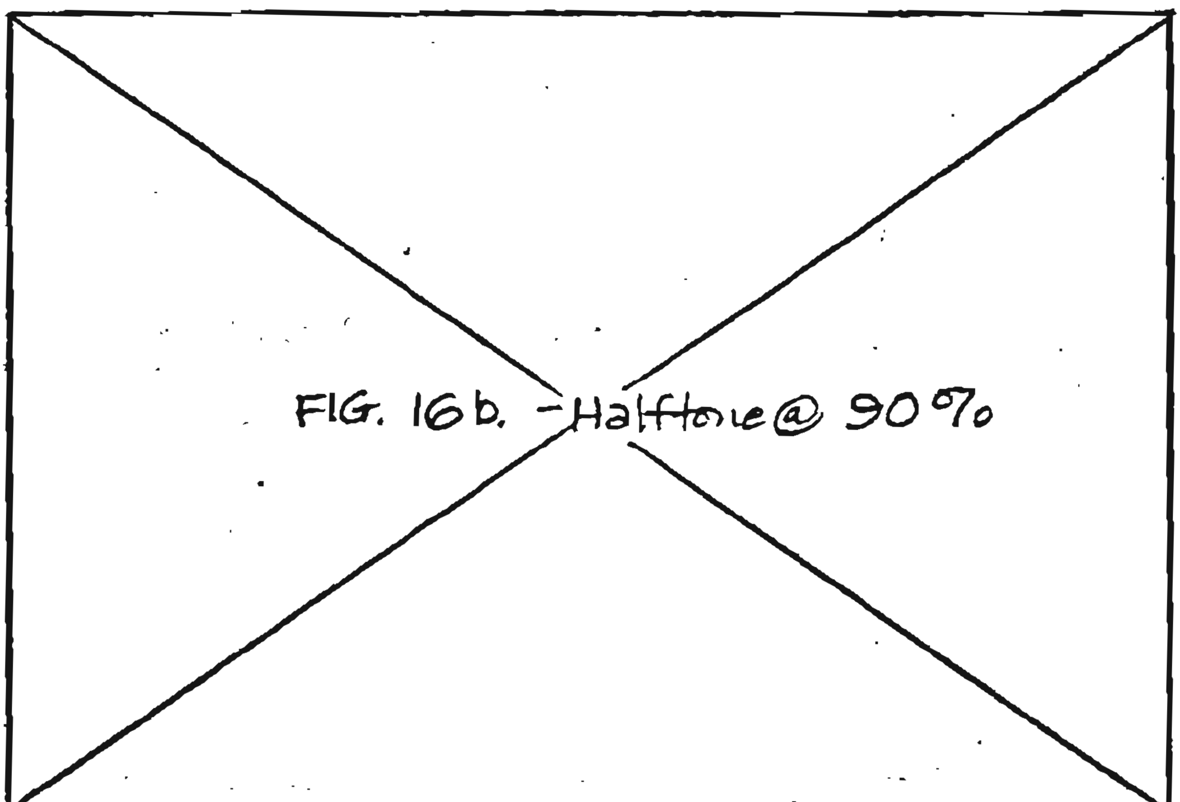


Figure 16.-- Site 14, Turner River.

$4\frac{1}{16} \times 6\frac{1}{4}$

Fig. 16a - Halftone @ 95%

4 1/16 x 5 7/8

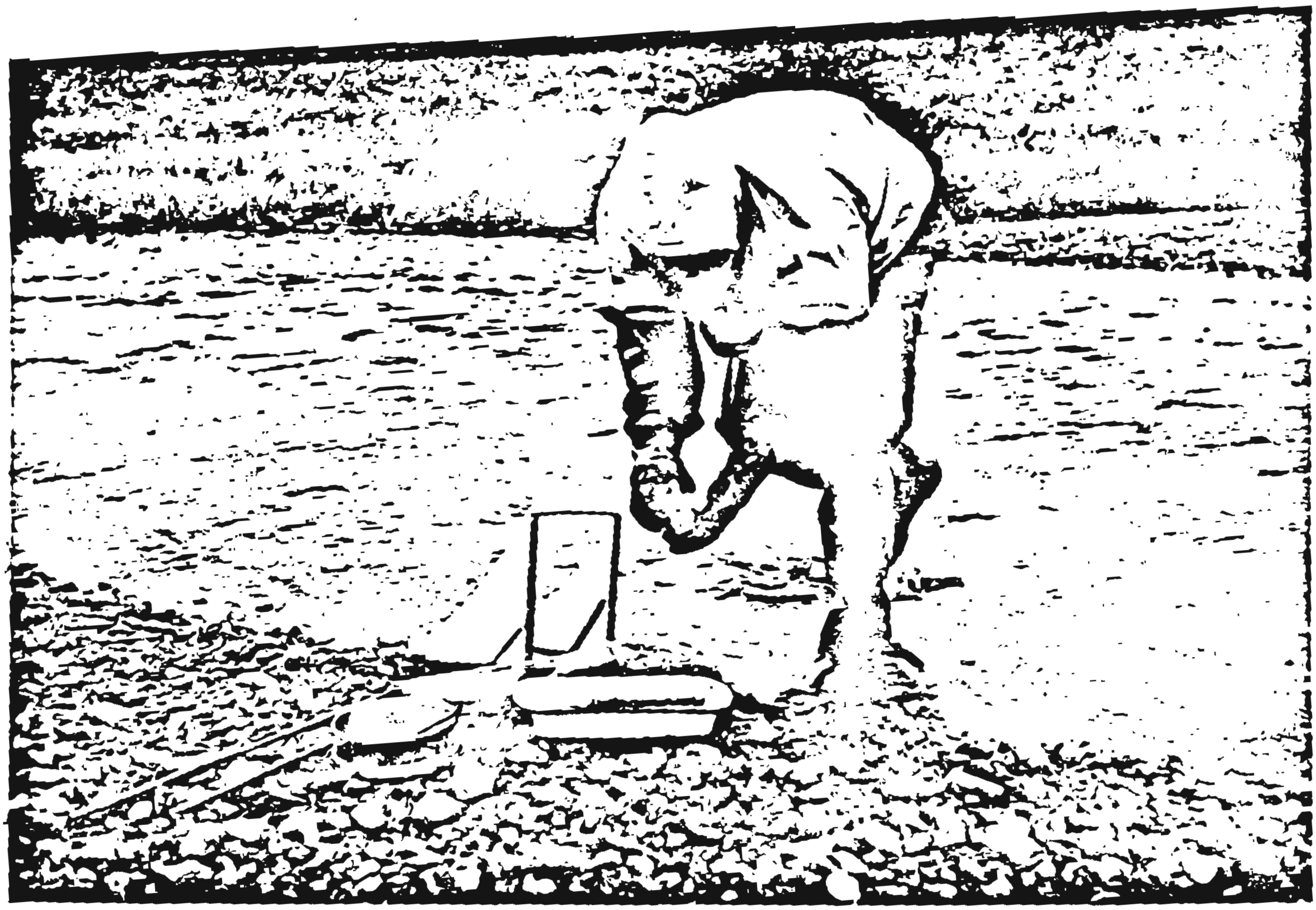


Fig. 16 b- Halftone @ 90 %

Bankfull stage was determined as the observed surface of the flood plain (Leopold and Skibitzke, 1967). Discharge was estimated by slope-conveyance methods (Dalrymple and Benson, 1967).

The physical and climatic drainage basin characteristics shown in table 1 include:

Area of glaciers (G) in percentage of drainage area.

Area of lakes and ponds (S_t) in percentage of drainage area.

Drainage area (A) in square miles, the total drainage area upstream from the stream site.

Main-channel slope (S) in feet per mile, the average slope between points 10 percent and 85 percent of the distance from the gaging site to the basin divide (stream length).

Mean annual precipitation (P) in inches, as determined from Searby (1968).

Mean basin elevation (E) in thousands of feet above sea level.

Mean minimum January temperature (t_1) in °F, from Searby (1968).

Precipitation intensity (I) in inches, the maximum rainfall expected in 24 hours each 2 years, from U.S. Weather Bureau (1963).

Stream length (L) in miles, the length of the main channel between the gaging station and the basin divide measured along the channel that drains the largest basin.

Table 1 shows the flood discharges for 2-year (Q_2) and 50-year (Q_{50}) average recurrence intervals. No streamflow records are available for the streams, so the flood discharges were estimated from multiple-regression equations relating flood discharges to drainage basin physical and climatic characteristics (Childers, 1970).

Maximum evident flood-peak discharge may be divided by drainage area to give unit runoff rates. The unit runoff rates shown in table 1 average about 40 $(ft^3/s)/mi^2$ [0.4 $(m^3/s)/km^2$]; the maximum rate is 185 $(ft^3/s)/mi^2$ [1.8 $(m^3/s)/km^2$]. The maximum evident flood at Marsh Creek was much less than the bankfull discharge. This condition may be caused by lack of flood debris deposited during large floods which may occur when part of the channel is formed in snowbanks.

The calculated bankfull and maximum evident flood discharges generally exceed the estimates of Q_{50}. This indicates that the Alaska regional flood-frequency relation used to estimate Q_{50} probably should not be applied to the Arctic Coastal Plain. On the North Slope, drainage basin characteristics such as presence of continuous permafrost and the amounts and rates of precipitation and snowmelt are important, but their effects on flooding have not been evaluated.

Table 1.--*Bankfull channel, maximum evident flood, basin and flood characteristics at flood-survey sites, eastern Arctic Slope. Locations shown on figure 2.*

		BANKFULL CHANNEL						MAXIMUM EVIDENT FLOOD			*BASIN CHARACTERISTICS									FLOOD CHARACTERISTICS	
Map No.	Stream site	Streambed material	Slope (ft/ft)	Width (ft)	Mean depth (ft)	Max depth (ft)	Discharge (ft^3/s)	Width (ft)	Discharge (ft^3/s)	Unit runoff (ft^3/s) mi^2	G	S_t	A	S	F	E	t_1	I	L	Q_2 (ft^3/s)	Q_{50} (ft^3/s)
1	Colville River 70°09'56" 150°05'50"	fine gravel	0.00056	2,240	25.2	57	683,000	2,230	600,000	29.0	0	3	20,670	6.[illegible]	7	1.6	-18	.75	380	55,000	105,000
2	Shaviovik River 70°05'07" 147°16'30"	coarse cobble	0.0012	1,510	4.2	7	22,000	1,510	22,000	13.0	0	0	1,680	29.3	6	1.5	-20	.75	100	4,900	13,700
3	Canning River 69°50'38" 146°27'10"	large cobble	0.0012	960	6.9	14	31,000	1,150	53,000	28.3	0	0	1,871	33.0	5	3.3	-20	.6	106	4,400	13,500
4	Katakturuk River 69°52'25" 145°27'10"	coarse gravel	0.0064	680	3.7	7	17,000	670	10,000	43.9	0	0	228	65.8	5	2.3	-20	.6	30	560	2,800
5	Marsh Creek 69°47'32" 144°49'00"	coarse gravel	0.0148	560	3.4	6	14,000	280	500	1.9	0	0	261	36.4	5	1.5	-20	.6	11	750	3,100
6	Sadlerochit River 69°39'13" 144°12'10"	boulders	0.0062	280	4.5	7	11,000	280	11,000	20.8	0	0	529	47.5	5	3.3	-20	.6	54	1,400	5,200
7	Hulahula River 69°41'47" 144°12'10"	coarse gravel	0.0050	250	7.2	9	23,000	240	10,000	14.7	5	0	682	41.7	5	4.2	-20	.6	68	1,800	6,300
8	Jago River 69°37'02" 143°41'06"	boulders	0.0132	180	5.9	7	14,000	180	14,000	43.6	8	0	321	70.5	5	4.3	-20	.75	52	1,000	3,800
9	Okerokovik River 69°42'07" 143°14'23"	coarse gravel	0.0033	590	3.4	7	10,000	360	2,300	13.6	0	0	169	63.2	6	1.6	-20	.75	24.8	650	2,600
10	Aichilik River 69°35'23" 142°58'03"	coarse gravel	0.0054	820	5.5	8	133,000	817	27,000	48.0	0	0	563	58.0	6	3.7	-20	.75	54	1,900	6,300
11	Egaksrak River 69°32'05" 142°41'05"	large cobble	0.0093	560	2.4	6	9,000	560	9,000	41.9	0	0	215	62.0	7	2.7	-20	.75	44	910	3,400
12	Ekaluakat River 69°34'35" 142°18'38"	medium gravel	0.0109	730	3.1	6	23,000	860	27,000	185.0	0	0	146	58.3	7	2.1	-20	.75	16	640	2,600
13	Kongakut River 69°30'54" 142°42'34"	coarse gravel	0.0058	2,770	4.6	9	98,000	2,770	98,000	79.0	0	0	[illegible],240	33.0	7	3.5	-20	.75	[illegible]	4,400	12,800
14	Turner River 69°35'56" 141°24'10"	medium gravel	0.0038	160	1.7	6	1,300	170	1,500	29.4	0	0	51	73.1	7	.481	-20	1.00	9	290	1,200

*Basin characteristics defined on page 19.

SPRINGS AND ICINGS

General Description

Springs and related icings are the most conspicuous active hydrologic features on the eastern Arctic Slope during the winter season. Streamflow virtually ceases in winter except in zones of ground-water discharge and channel reaches immediately downstream from concentrated points of ground-water discharge (springs).

During winter, spring water freezes downstream from its source to form icings. The area, thickness, and location of an icing depend basically on the volume of water supplied and to a lesser extent on water temperature, air temperature, and topography of the ice accumulation area.

The locations of several of the more conspicuous springs, such as Shublik and Sadlerochit, were known from reports in the literature (Williams, 1970). Marvin Mangus (oral commun., 1972), geologist in Anchorage with extensive field experience in the eastern Brooks Range, told us the location of several other springs, including the one at Red Hill. The location and extent of icings in the Sagavanirktok, Ivishak, Canning, Tamayariak, Katakturuk, Sadlerochit, and Hulahula River drainage basins were observed during an aerial reconnaissance. Landsat I (originally called ERTS A) satellite imagery was used to locate icings in tundra north of the Brooks Range. On Landsat I, ice or water surfaces appear black against a white snow background in winter scenes. There is very little black and white contrast in visible Band 4 (0.4 to 0.5 micrometers) of the multispectral scanner; on the other hand, the contrast is most pronounced in the near-infrared Band 7 (0.8 to 1.1 micrometers).

Icings melt more slowly than snow cover, and some large icings persist from year to year. Figure 17 shows remnants of the Ekaluakat icing in late July 1975. In summer, the remnants of icings are in bright contrast to surrounding soil and vegetation and can be readily identified on Landsat I images (fig. 18) in Band 5 (0.6 to 0.7 micrometers).

Before the reconnaissance trips were undertaken, available Landsat imagery was studied to identify and locate icings on the eastern Arctic Slope. These icing sites were used as the basis for planning the winter hydrologic reconnaissance. At each location, the expected icings and open water leads from nearby springs were found. An example of such an open water lead can be seen in figure 19. Figure 20 shows the locations of the main springs and icings in the study area.

At each spring, discharge was measured, field determinations of conductance, pH, alkalinity, temperature, and dissolved oxygen were made, and samples were collected for analysis of total organic carbon, turbidity, color, and selected inorganic chemical parameters. Aquatic invertebrates were also collected for laboratory analysis.

(Selected water-quality data for springs, streams, and lakes are presented in tables 2, 3, and 4, respectively. The map numbers in these tables refer to figures 20, 26, and 27, which show the location of the springs, stream, and lake sampling sites, respectively.)

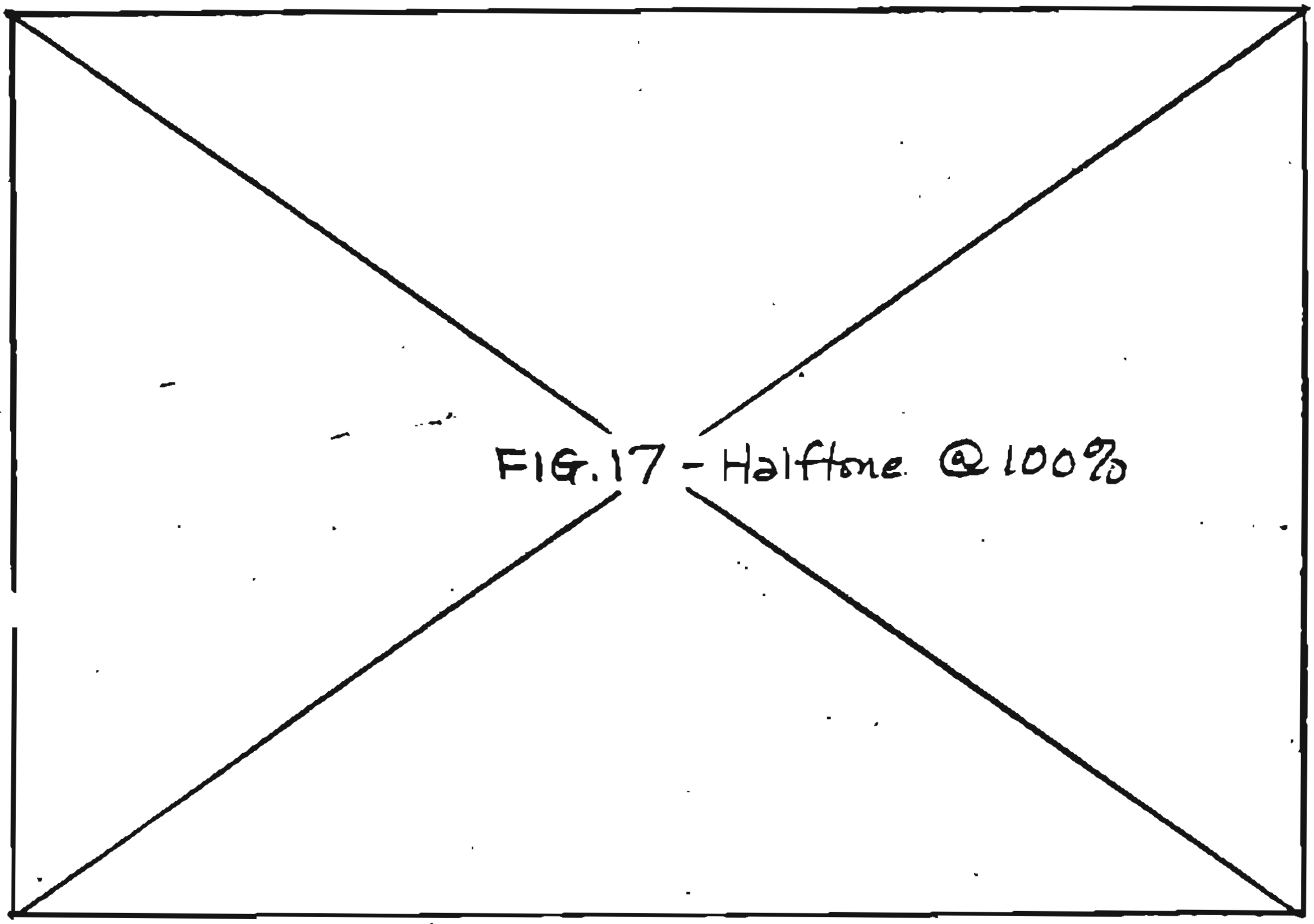


Figure 17.-- Ekaluakat icing remnants, July 1975.

Fig. 17 - 100% Halftone

FIG. 18 - Halftone @ 100%

Figure 18.-- Landsat I image of Kongakut icing, August 1, 1973.

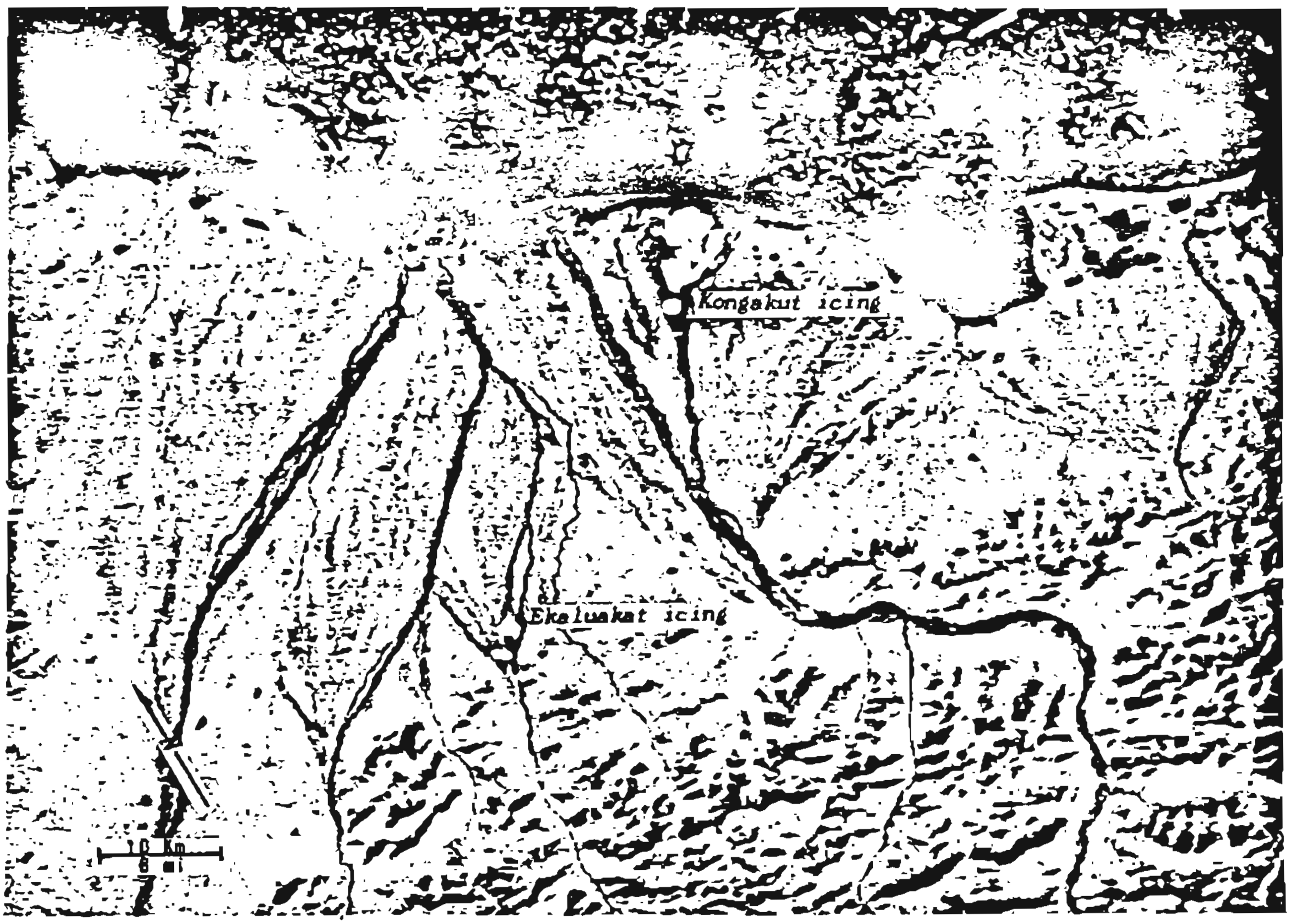


Fig. 18 - Halftone @ 100%

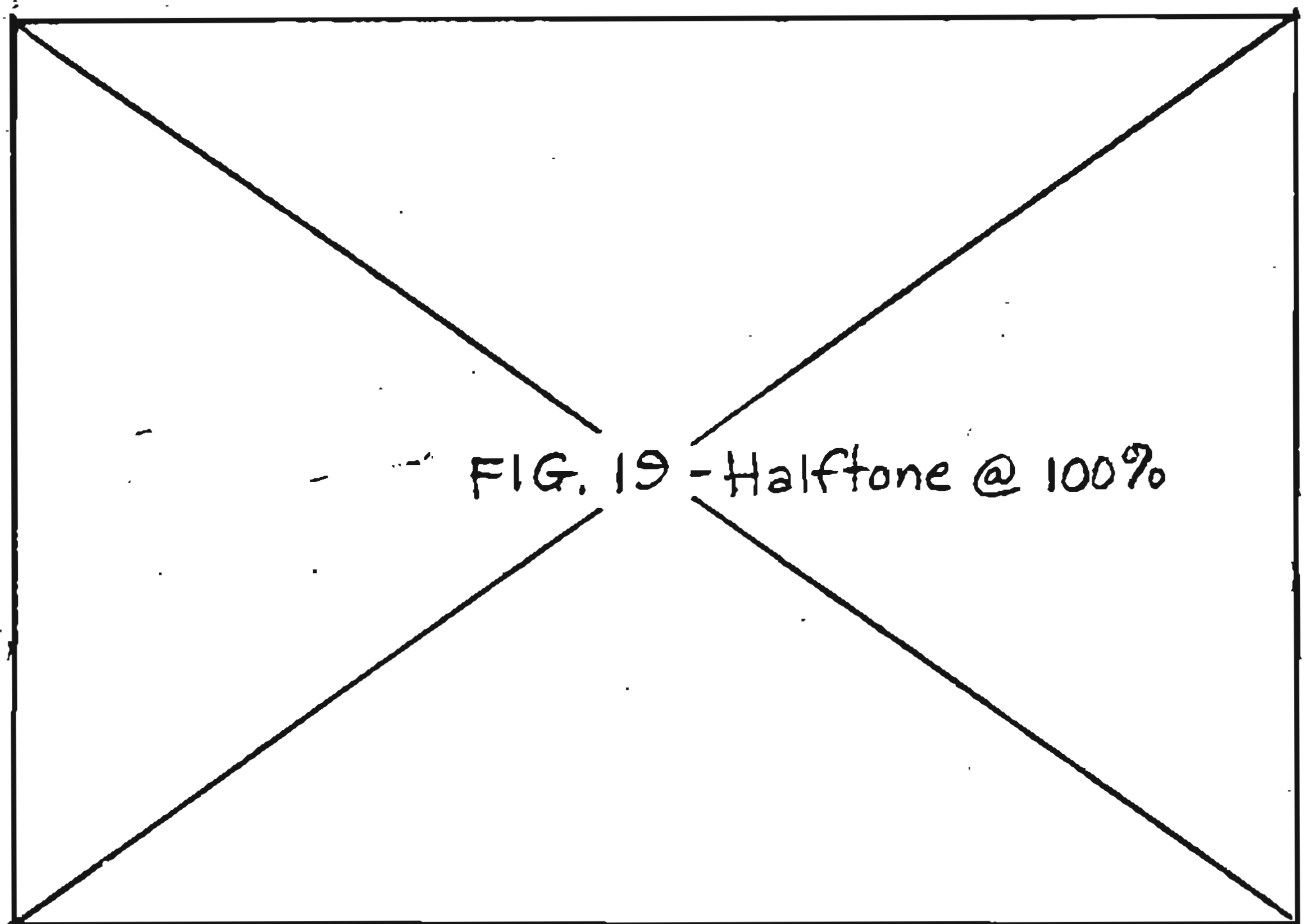


Figure 19.-- Open water at spring that feeds the Ekaluakat icing, April 22, 1975.

Fig. 19 - 100% Halftone

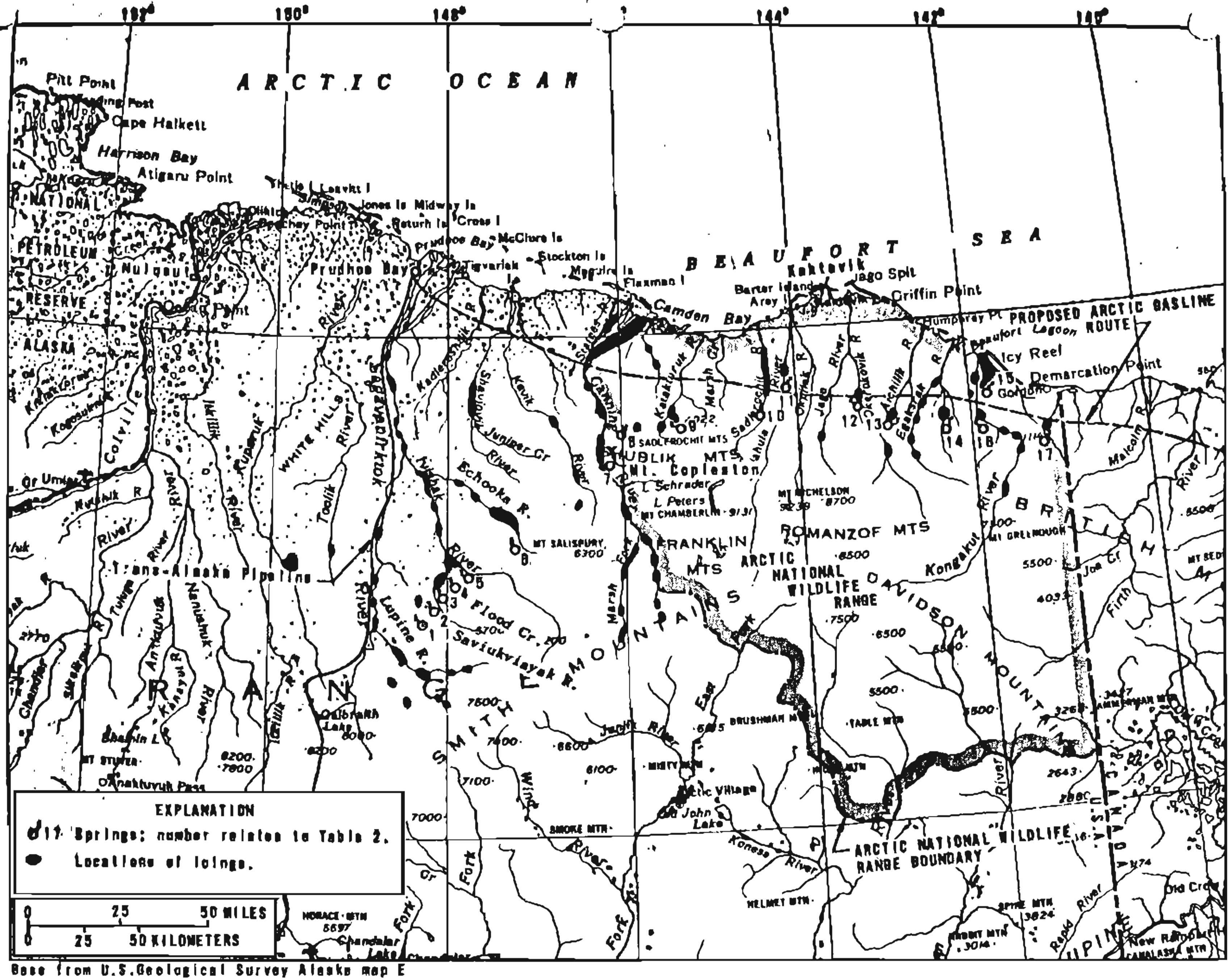


Figure 20.--Location of springs and icings.

A distinctive feature of most of the springs on the North Slope is the luxuriant growth of vegetation, both aquatic and riparian, much of which stays a bright green even in winter. Willow growth is thick near many springs, and at some of the springs are stands of balsam poplar up to 40 ft (12 m) tall.

Some of the springs that flow from alluvial deposits are surrounded in winter by bare gravel which makes them relatively easy to spot from the air. There is apparently enough heat in the water and in the ground to melt any snow that falls there.

The discharge measurements of spring systems were made at a point downstream so as to integrate the flow of all upstream springs. Samples for chemical analysis were taken at a single representative orifice that could be readily identified and resampled. Temperature and dissolved-oxygen measurements of each spring were made as close to the discharge point as possible.

Sagavanirktok River System Springs

Many springs occur in tributary basins of the Sagavanirktok River along the northern edge of the Brooks Range. A general description of these springs is given in Childers and others (1973).

Echooka springs at the edge of the mountains supply the largest icing in the Sagavanirktok drainage basin, one of the largest icings in Alaska. Echooka springs were discharging about 100 ft^3/s (2.83 m^3/s) in May 1973.

In winter months discharge from springs in the Saviukviayak River, Flood Creek, and in Ivishak River drainages near the mountain front (fig. 21) coalesces to form a large and conspicuous icing near their confluence. Cumulative discharge from these springs in May 1973 amounted to nearly 370 ft^3/s (10.5 m^3/s). Measurement of these same springs in April 1975 indicated a total discharge of about 200 ft^3/s (5.7 m^3/s). This wide difference in flow was probably the result of early snowmelt runoff in 1973. Use of the 1975 data (table 2) gives a more conservative figure for minimum spring discharge.

The Saviukviayak tributary has a drainage basin of about 32 mi^2 (83 km^2) and had a spring-flow discharge in April of 45 ft^3/s (1.3 m^3/s). If this value is a representative figure for minimum ground-water discharge in the basin, it would be equivalent to an annual basin yield of about 1.6 ft (0.5 m) of water over the entire basin, assuming that the ground-water basin coincides with the surface-water basin. This assumption is probably not valid because the adjacent Flood Creek basin [drainage area 80 mi^2 (207 km^2)] had a spring-flow discharge of 53.6 ft^3/s (1.5 m^3/s) in April 1975. This is equivalent to an annual basin yield of about 0.8 ft (0.2 m) of water. If this is combined with the adjacent Saviukviayak tributary basin, a yield of about 1.0 ft (0.3 m) of water for the two basins results. Estimated average annual precipitation for the area is between 1.5 and 3 ft (0.5 and 1.0 m). Thus it can be seen that ground-water discharge is a very significant part of the hydrologic regime of this part of Alaska.

Table 2.--*Dissolved chemical constituents and physical parameters for springs, eastern Arctic Slope (all constituents reported in mg/L unless otherwise specified).*

Map No. from fig. 20	1	2	3		4	
Station name	Lupine spring	Saviukviayak R. west spr.	Saviukviayak trib. spring		Flood Creek spring	
Latitude	68°51'45"	68°54'10"	68°56'20"		68°58'40"	
Longitude	148°12'20"	148°05'10"	147°58'45"		147°51'30"	
Date	05-09-73	05-05-73	05-10-73	04-20-75	05-10-73	04-20-75
Time	--	--	--	10:00	--	14:15
Discharge (ft^3/s)	1.5	89	54	45	83	54
Silica	3.7	4.8	4.6	4.8	6.3	5.3
Iron (µg/L)	30	60	50	--	30	--
Manganese (µg/L)	0.0	0.0	10	--	0	--
Calcium	51	40	39	52*	38	52*
Magnesium	7.7	9.2	7.3	--	8.8	--
Sodium	0.4	0.7	0.3	0.8	0.4	0.3
Potassium	0.1	0.1	0.1	0.5	0.1	0.5
Bicarbonate	177	155	137	145	136	131
Carbonate	0.0	0.0	0.0	--	0	--
Alkalinity, total ($CaCO_3$)	145	127	112	--	112	--
Sulfate	12	8.5	12	9.1	14	11
Chloride	2.8	0.7	0.5	0.9	1.3	0.9
Fluoride	0.3	0.5	0.5	0.3	0.6	0.4
Nitrate and nitrite as N	0.13	0.05	0.05	0.11	0.05	0.11
Orthophosphorus as P	0.00	0.00	0.00	0.03	0.00	0.01
Dissolved solids (sum of determined constituents)	166	141	132	--	137	--
Hardness, total	160	140	130	130	130	130
Non-carbonate hardness	14	11	15	--	20	--
Specific conductance (micromhos/cm at 25°C)	298	259	239	247	240	222
pH (units)	7.8	7.8	7.9	8.2	8.2	8.0
Water temperature (°C)	2.5	5.0	3.5	6.5	8.5	7.2
Color (platinum-cobalt units)	1.0	1.0	1.	0.	1	0
Turbidity (Jackson Turbidity units)	--	--	--	1	--	2
Dissolved oxygen	--	--	--	8.9	--	9.0
Total organic carbon	--	--	--	--	--	9.9

*Calcium and magnesium (calculated as calcium)

Table 2.--*Dissolved chemical constituents and physical parameters for springs, eastern Arctic Slope (all constituents reported in mg/L unle otherwise specified).*

Map No. from fig. 20	5		6	7		8	
Station name	Ivishak hillside spring		Echooka R. west spring	Shublik spring		Red Hill spring	
Latitude	69°01'50"		69°15'35"	69°28'20"		69°37'37"	
Longitude	147°43'00"		147°22'50"	146°11'50"		146°01'38"	
Date	05-11-73	04-20-75	05-10-73	05-10-73	04-28-75	04-28-75	08-12-75
Time	--	15:40	11:00	--	14:00	12:45	13:45
Discharge (ft^3/s)	194	74	22	24	24	0.85	--
Silica	5.8	4.9	5.8	4.8	--	29	27
Iron (µg/L)	20	--	50	50	--	--	0
Manganese (µg/L)	10	--	0	0	--	--	0
Calcium	36	47*	36	38	--	--	55
Magnesium	9.1	--	9.8	11	--	--	21
Sodium	0.4	0.4	1.3	1.5	--	130	120
Potassium	0.1	0.4	0.2	0.3	--	5.9	5.8
Bicarbonate	137	128	131	127	124	--	322
Carbonate	0	--	0	0	--	--	0
Alkalinity, total ($CaCO_3$)	112	--	107	104	--	--	--
Sulfate	13	8.9	24	37	--	90	50
Chloride	0.6	0.3	1.3	1.3	--	150	130
Fluoride	0.6	0.04	0.3	0.5	--	1.1	1.0
Nitrate and nitrite as N	0.04	0.08	0.03	0.03	--	0.01	0.02
Orthophosphorus as P	0.00	0.00	0.00	0.00	--	0.03	0.01
Dissolved solids (sum of determined constituents)	133	--	143	157	--	--	569
Hardness, total	130	118	130	140	140-	--	220
Non-carbonate hardness	15	--	23	36	--	--	0
Specific conductance (micromhos/cm at 25°C)	238	252	257	275	270	1,000	950
pH (units)	8.0	7.5	7.9	8.0	7.9	7.0	8.2
Water temperature (°C)	7.5	0	7.0	5.5	5.5	33.0	29.0
Color (platinum-cobalt units)	1	--	1	1	0	0	2
Turbidity (Jackson Turbidity units)	--	8.7	--	--	1	2.0	--
Dissolved oxygen	--	5.3	--	--	9.8	0.4	--
Total organic carbon	--	--	--	--	0.8	--	--

*Calcium and magnesium (calculated as calcium)

Table 2.--*Dissolved chemical constituents and physical parameters for springs, eastern Arctic Slope (all constituents reported in mg/L unless otherwise specified).*

Map No. from fig. 20	9	10			11		12
Station name	Katakturuk R. trib spring	Sadlerochit spring			Hulahula R. icing spring		Okerokovik R. spring
Latitude	69°41'42"	69°39'23"			69°45'39"		69°43'06"
Longitude	145°06'33"	144°23'37"			144°09'15"		143°14'25"
Date	04-28-75	04-27-75	08-07-75	11-16-75	04-28-75	11-26-75	11-24-75
Time	11:15	16:30	14:00	--	10:00	--	--
Discharge (ft^3/s)	4.28	35	37.4	38.7	7.3	4.6	26
Silica	4.3	10	10	9.5	3.1	1.5	3.3
Iron (µg/L)	3.3	--	30	--	--	--	--
Manganese (µg/L)	--	--	0	--	--	--	--
Calcium	52*	78*	47	--	51	--	--
Magnesium	--	--	18	--	--	--	--
Sodium	0.5	8.2	7.8	6.9	1.8	0.8	1.1
Potassium	0.5	1.1	1.0	0.5	0.7	0.2	0.3
Bicarbonate	130	156	140	126	116	66	163
Carbonate	--	--	0	--	--	--	--
Alkalinity, total ($CaCO_3$)	--	--	115	--	--	--	--
Sulfate	1.8	71	66	61	27	18	22
Chloride	0.8	4.0	3.5	3.6	1.3	0.7	1.3
Fluoride	0.1	0.7	0.6	--	0.4	--	--
Nitrate and nitrite as N	0.08	0.05	0.07	0.10	0.1	0.10	.31
Orthophosphorus as P	0.00	0.00	0.01	0.01	0.01	0.03	0.00
Dissolved solids (sum of determined constituents)	--	--	223	--	--	--	--
Hardness, total	130	190	190	--	126	--	--
Non-carbonate hardness	--	--	77	--	--	--	--
Specific conductance (micromhos/cm at 25°C)	245	410	400	360	240	225	300
pH (units)	8.2	7.9	7.3	7.3	8.0	7.2	7.3
Water temperature (°C)	1.0	13.0	13.0	4.0**	1.0	1.0	1.0
Color (platinum-cobalt units)	0	0	4	--	0	--	--
Turbidity (Jackson Turbidity units)	1	1	--	--	1	--	--
Dissolved oxygen	11.4	7.0	6.2	--	13.6	--	--
Total organic carbon	2.1	0.7	0.7	--	1.7	--	--

*Calcium and magnesium (calculated as calcium)

**measured about 1 mile downstream from spring

Table 2.--*Dissolved chemical constituents and physical parameters for springs, eastern Arctic Slope (all constituents reported in mg/L unless otherwise specified).*

Map No. from fig. 20	13	14	15	16	17	18	
Station name	Aichilik R. spring	Ekaluakat R. spring	Kongakut R. delta spring	Kongakut R. above delta	Kongakut R. spring	Clarence R. spring	
Latitude	69°31'06"	69°35'27"	69°43'36"	69°42'50"	69°32'36"	69°30'44"	
Longitude	143°02'00"	142°18'00"	141°46'07"	141°47'30"	141°49'38"	141°11'37"	
Date	04-27-75	04-22-75	04-27-75	11-18-75	04-27-75	04-27-75	11-18-7
Time	13:30	10:00	12:00	--	10:00	10:50	--
Discharge (ft^3/s)	1.5	5.1	37	88.4	13	0.5	4.7
Silica	2.4	3.9	2.7	3.0	2.3	2.3	2.2
Iron (µg/L)	--	--	--	--	--	--	--
Manganese (µg/L)	--	--	--	--	--	--	--
Calcium	65*	69*	46*	--	50	53*	--
Magnesium	--	4.5	1.1	--	1.0	--	0.7
Sodium	2.8	.6	1.1	1.1	0.5	0.5	0.3
Potassium	2.1	--	--	0.1	--	--	--
Bicarbonate	148	165	122	62	134	124	86
Carbonate	--	--	--	--	--	--	--
Alkalinity, total ($CaCO_3$)	--	--	--	--	--	--	--
Sulfate	39	25	17	17	25	12	26
Chloride	2.0	3.6	0.5	1.0	0.9	0.7	1.4
Fluoride	0.2	0.4	0.1	--	0.1	0.0	--
Nitrate and nitrite as N	0.08	0.07	0.14	0.16	0.08	0.05	.16
Orthophosphorus as P	0.19	0.00	0.11	0.00	0.00	0.00	0.00
Dissolved solids (sum of determined constituents)	--	--	--	--	--	--	--
Hardness, total	162	172	116	--	--	132	--
Non-carbonate hardness	--	--	--	--	--	--	--
Specific conductance (micromhos/cm at 25°C)	338	350	215	210	276	--	250
pH (units)	8.0	7.9	7.9	6.7	7.9	7.9	6.8
Water temperature (°C)	3.6	6.4	1.0	0.5	1.0	--	0.0
Color (platinum-cobalt units)	0	0	0	--	0	--	--
Turbidity (Jackson Turbidity units)	2	1	1	--	1	--	--
Dissolved oxygen	12.4	8.1	12.2	--	13.0	--	--
Total organic carbon	1.2	4.9	0.9	34	3.9	6.3	--

*Calcium and magnesium (calculated as calcium)

FIG. 21 - Enlarge 120% Halftone

Figure 21.-- Ivishak hillside spring, April 20, 1975.

Fig. 21 - Enlarge 120%
Halftone

No single spring orifice in the Sagavanirktok drainage system discharges a very large volume of water. Instead, numerous springs discharge at or near the valley bottoms from exposed bedrock or stream-channel alluvium. In some places, springs such as the Ivishak hillside spring (fig. 21) and some springs in Flood Creek valley issue from steep banks several tens of feet above the adjacent stream.

Canning River System Springs

The cumulative discharge of springs in the Canning River and its tributaries is probably greater than in any other river system on the North Slope in Alaska. Shublik Spring, which discharges about 24 ft^3/s (0.68 m^3/s) on the southwest end of Copleston Mountain, emerges from two main orifices and descends in a channel about 300 ft (90 m) in half a mile to the point where it plunges the last 40 ft (12 m) into the Canning River (fig. 22).

In late winter, icings formed by these springs are almost continuous from the upper reaches of the Marsh Fork of the Canning River throughout the entire length of the main river channel. One of the largest icings in the area forms in the distributary channels of the Canning and the Staines Rivers upstream from their delta.

Red Hill Spring

Red Hill spring at the west end of the Sadlerochit Mountains is one of the few known hot springs on the Arctic Slope. Water temperature at the main orifice was 32.8°C in April 1975 and 29.3°C in August. Gases bubble to the surface in the orifice pool, and there is a strong odor of hydrogen sulfide at the spring. Lavender and cream-colored algae coat the rocks and bottom of the pool. The water has a slightly bluish, turbid appearance. The spring water flows across and through a rubble slope for about 300 ft (90 m) to join the spring-fed headwaters of the Tamayariak River. The headwater stream contains an unidentified suspended "precipitate" and appears black. Discharge in the stream was measured at 0.85 ft^3/s (0.02 m^3/s) in April 1975. Water quality was sampled at the spring orifice.

Sadlerochit Spring

Sadlerochit Spring at the east end of the Sadlerochit Mountains (fig. 23) is the largest known spring on the Arctic Slope to issue from a hillside bedrock source. Fairly constant discharge of about 37 ft^3/s (1.05 m^3/s) issues at nearly 13°C from a primary orifice and one secondary orifice in talus derived from the Sadlerochit Sandstone (fig. 35). The spring maintains an open channel for nearly 50 mi (80 km) downstream even during the coldest part of the year because of its high discharge and temperature. A narrow, thick and elongated icing develops about 5 mi (8 km) downstream from the spring and extends for another 5 mi (8 km) down the valley.

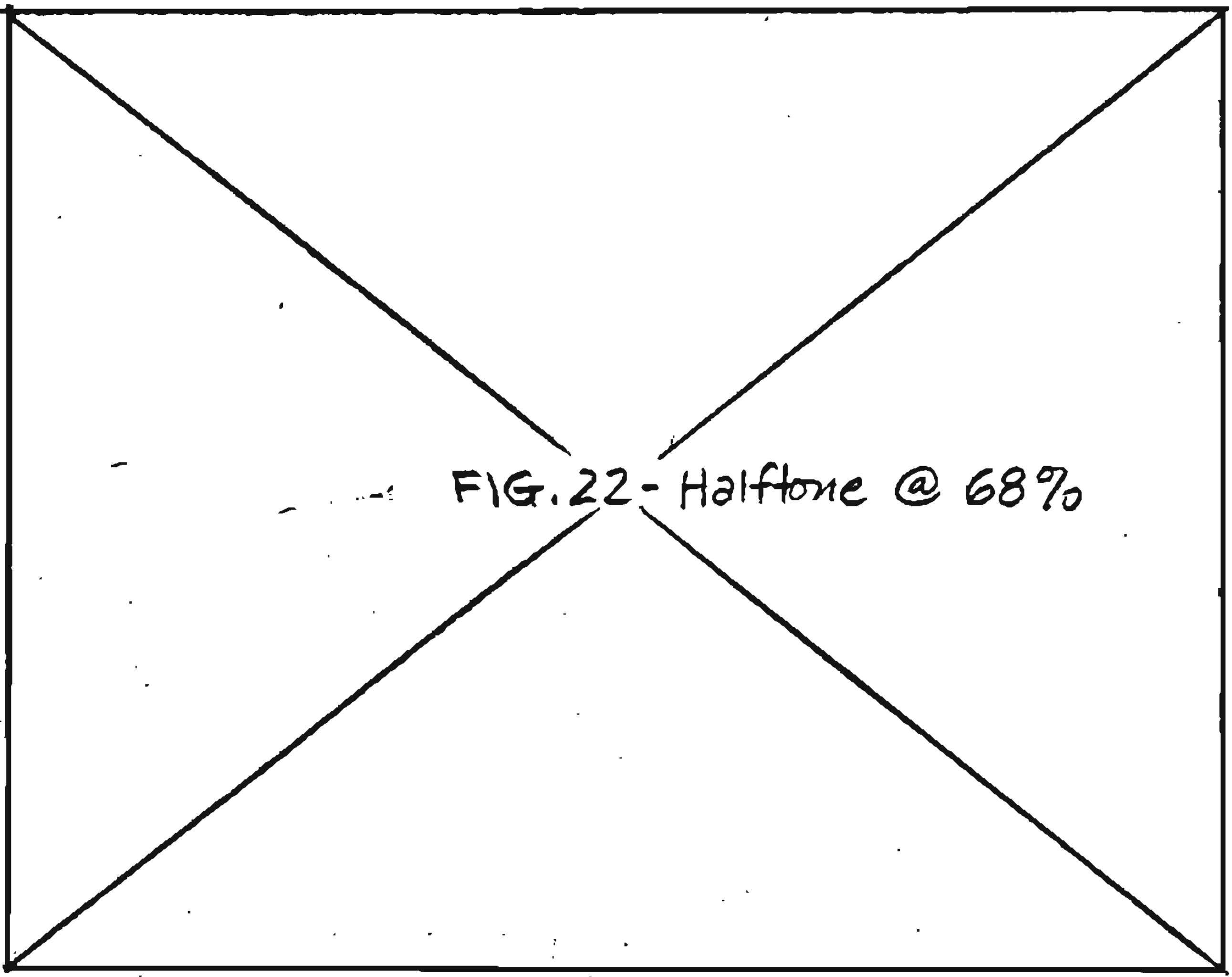


Figure 22.-- Shublik Spring where it discharges to Canning River, April 28, 1975.

FIG. 22 [illegible]

Kongakut River Springs

The largest icing known in Alaska occurs in the lower distributary reaches of the Kongakut River (fig. 18). This fan-shaped icing develops from several large springs that emerge from an alluvial fan surface. In November 1975, a combined discharge of 88.4 ft^3/s (2.5 m^3/s) was measured in two channels at the head of the icing, and another channel was flowing at an estimated 15 ft^3/s (0.42 m^3/s). In April 1975, a flow of 37 ft^3/s (1.05 m^3/s) was measured in a single channel near the head of the icing. Freshwater from the springs overflows sea ice in the lagoon behind Icy Reef and extends the icing laterally for at least 10 mi (16 km) along the coast. The size of the icing as delineated on Landsat I imagery is estimated to be about 50 mi^2 (130 km^2).

Some springs, such as those that feed the Kongakut, Canning, Okerokovik, and Hulahula icings near the proposed Arctic Gas pipeline route, emerge from alluvial deposits and have no apparent relationship to any bedrock outcrops or structure. Furthermore, there is no apparent geomorphic setting such as a channel constriction or change of slope to explain the location of the springs. Thus the question is raised whether these springs have their source in buried bedrock at or near the places where they emerge.

Water Quality of Springs

The springs are, with few exceptions, remarkably uniform in their water quality (table 2). The water is of excellent quality for almost any use. The water is clear and turbidity is very low; pH ranges from 6.7 to 8.2. Dissolved-oxygen concentration is high, generally near saturation. For those springs in which discharge can be isolated from general runoff, such as the Sadlerochit and Shublik Springs, discharge and temperature seem to remain nearly constant. The water is a dilute calcium bicarbonate type, and dissolved-solids concentrations range from about 130 to 225 mg/L.

Red Hill spring is the principal exception to the above generalities. Its thermal waters are a sodium bicarbonate type, high in both chloride and sulfate. (The water in Sadlerochit Spring contains more sulfate than most other springs in the study area.)

Because their flow regime is relatively stable compared to streamflow, the springs support a varied and abundant flora and fauna. The springs are a source of water for overwintering habitats for fish, including Arctic char.

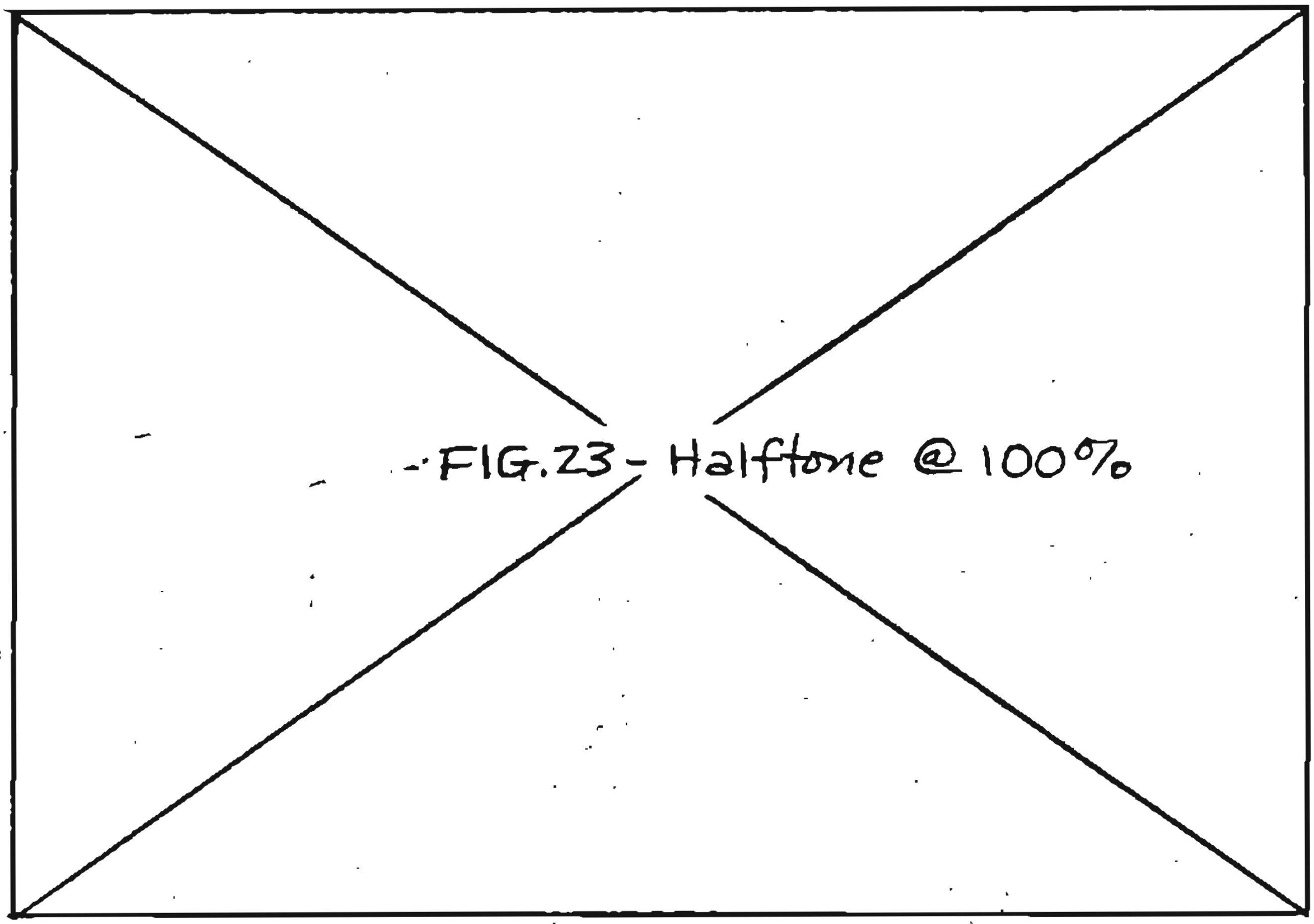


Figure 23.-- Sadlerochit Spring main orifice, August 7, 1975.

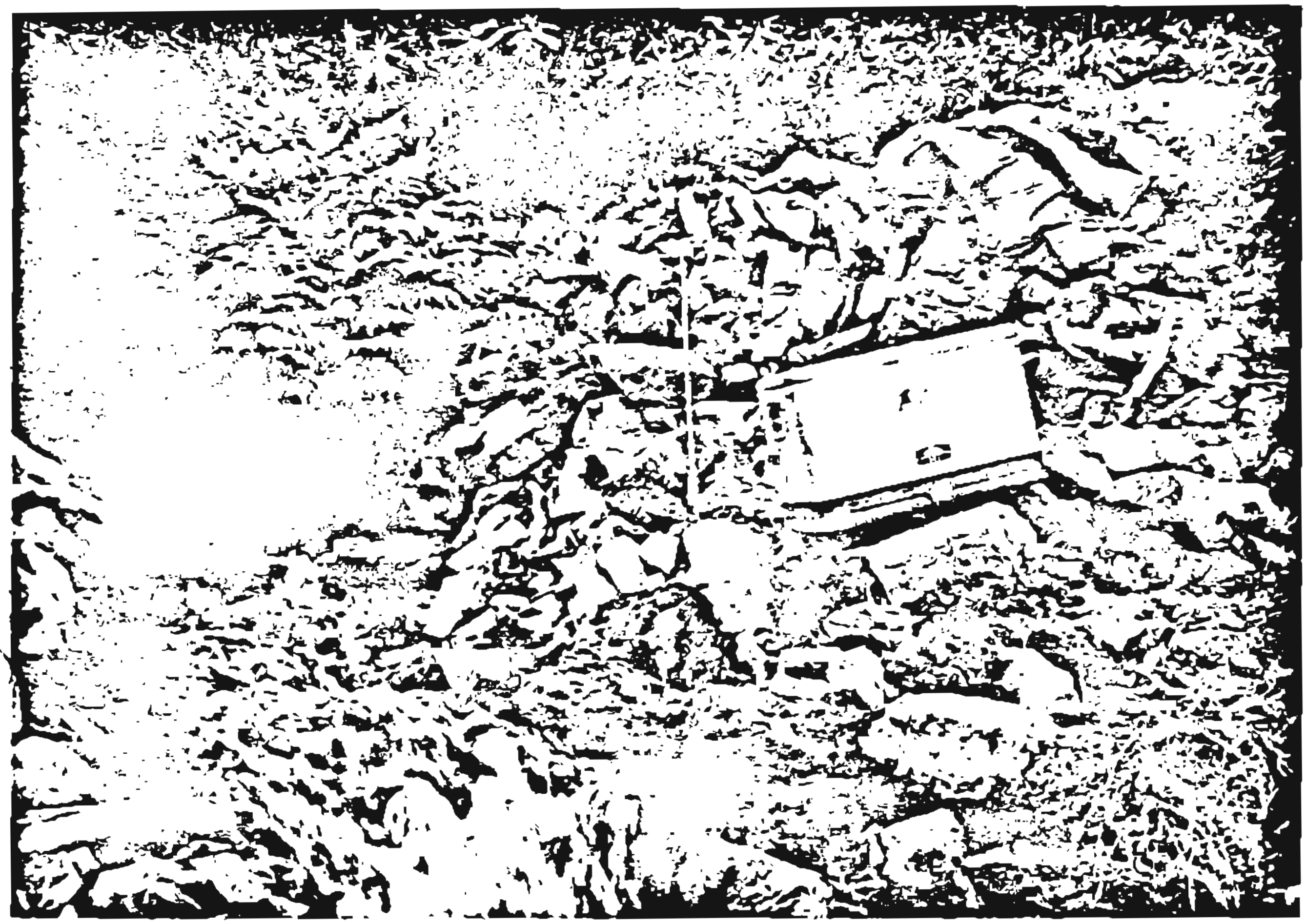


FIG. 23 - 100% Halftone

STREAMS

Streamflow is virtually nonexistent in most Arctic streams during the winter. Attempts to find and measure streamflow in the Colville River, the largest river on the North Slope, in April 1975 were unsuccessful. Water was found pooled under ice at Umiat and at the head of the delta near Nuiqsut (fig. 24), but movement could not be detected with a current meter. At another site near the mouth of the Anaktuvuk River, no water could be found in a section across the main channel, and ice above the gravel averaged less than 2 ft (0.6 m) thick.

During November 1975 intensive efforts to find and measure streamflow along the proposed Arctic Gas pipeline route revealed only seven locations with measurable flow. Five of these were in open leads at or near springs (see table 3). Figure 25 shows the locations of stream sites with no measurable winter flow.

During the reconnaissance trip in August 1975, streamflow was fairly low and the stream water was clear. The only noticeable turbidity found was in the Katakturuk River and resulted from a rainstorm in its headwaters on the preceding day. The streams in the eastern Arctic Slope have extremely coarse beds which are well armored with gravel, cobbles, and boulders. Even the banks consist of coarse material. Thus clear water conditions are probably the rule rather than the exception. The chemical quality of water in streams sampled during the summer visit was remarkably similar to that of the springs sampled in the same basins. The difference between specific conductance values in streams and springs in the same basin averaged less than 10 percent.

Streams in the area are in a pristine natural state. The locations of streams sampled are shown in figure 26 and water-quality data are shown in table 3. Dissolved oxygen is at or near saturation during open-water flow and becomes reduced only in stagnant pools under ice cover. Water temperature in August ranged from 2.7°C in the Katakturuk River to 9.8°C in the Colville; it averaged 6°C for the 14 streams measured. Except for the Turner and Colville Rivers, the streams sampled were virtually colorless.

LAKES

There are numerous shallow thaw lakes in the coastal plain region between the Colville and the Canning Rivers. To the east of the Canning River the area is fairly well drained; it has low rolling uplands and very few lakes. The locations of the lakes sampled are shown in figure 27. Most of the lakes in the coastal plain range from 3 to 6 ft (1 to 2 m) in depth and freeze to the bottom. Water depth listed in table 4 is the total depth of the lake at the point of sampling. Dissolved solids in the water of shallow lakes that do not freeze to the bottom become concentrated during the winter so that the water is unusable for most purposes bu late winter. Ice on Barter Island Lake was about 6 ft (2 m) thick in April 1975, leaving about 0.5 ft (0.2 m) effective depth beneath the ice. At that time the water had a specific conductance of 7,130 micromhos/cm at 25 °C and contained 1,600 mg/L of

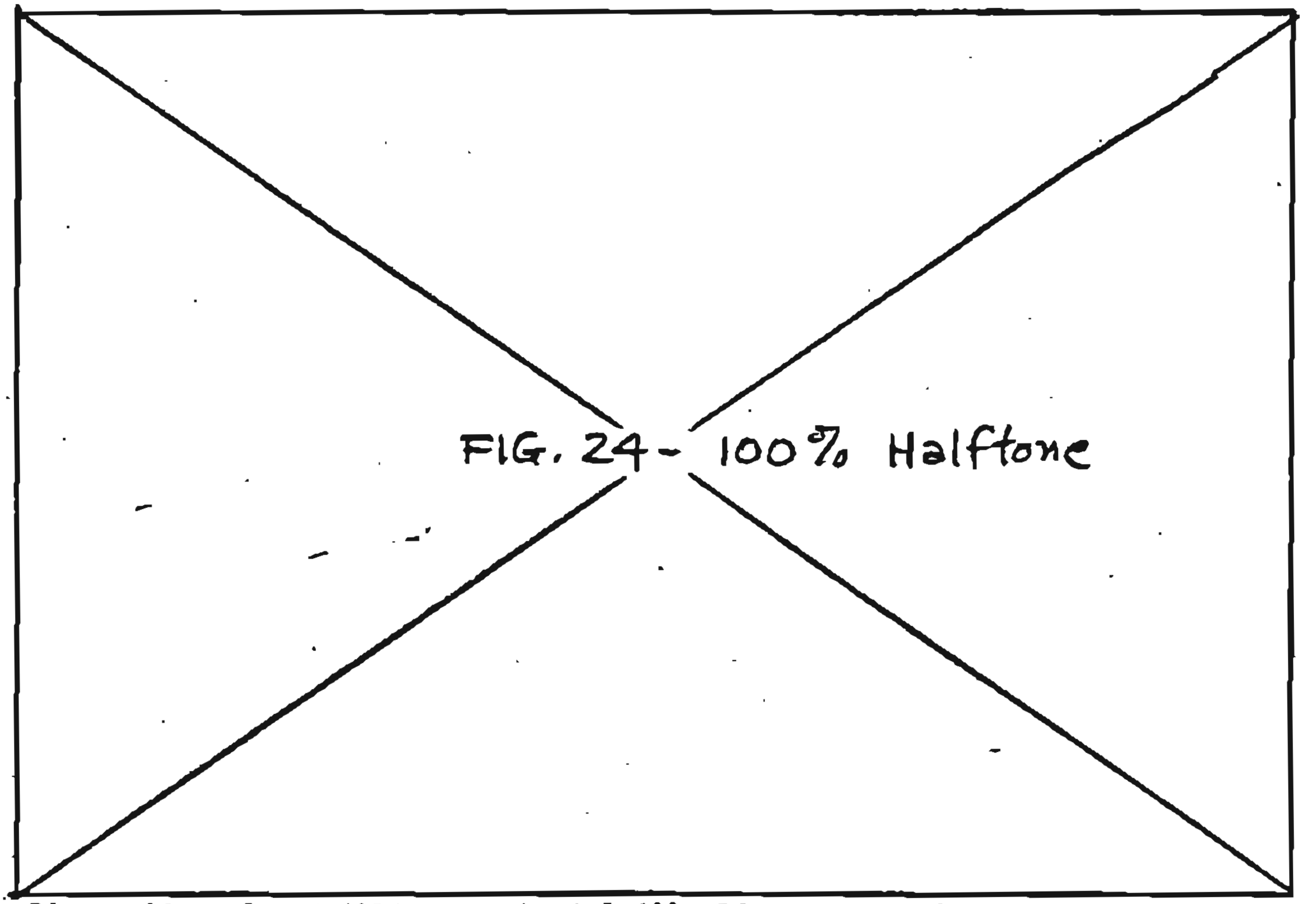


Figure 24.-- Ice drilling on the Colville River near Nuiqsut, April 25, 1975.
Ice thickness is about 7.3 ft (2.2 m).

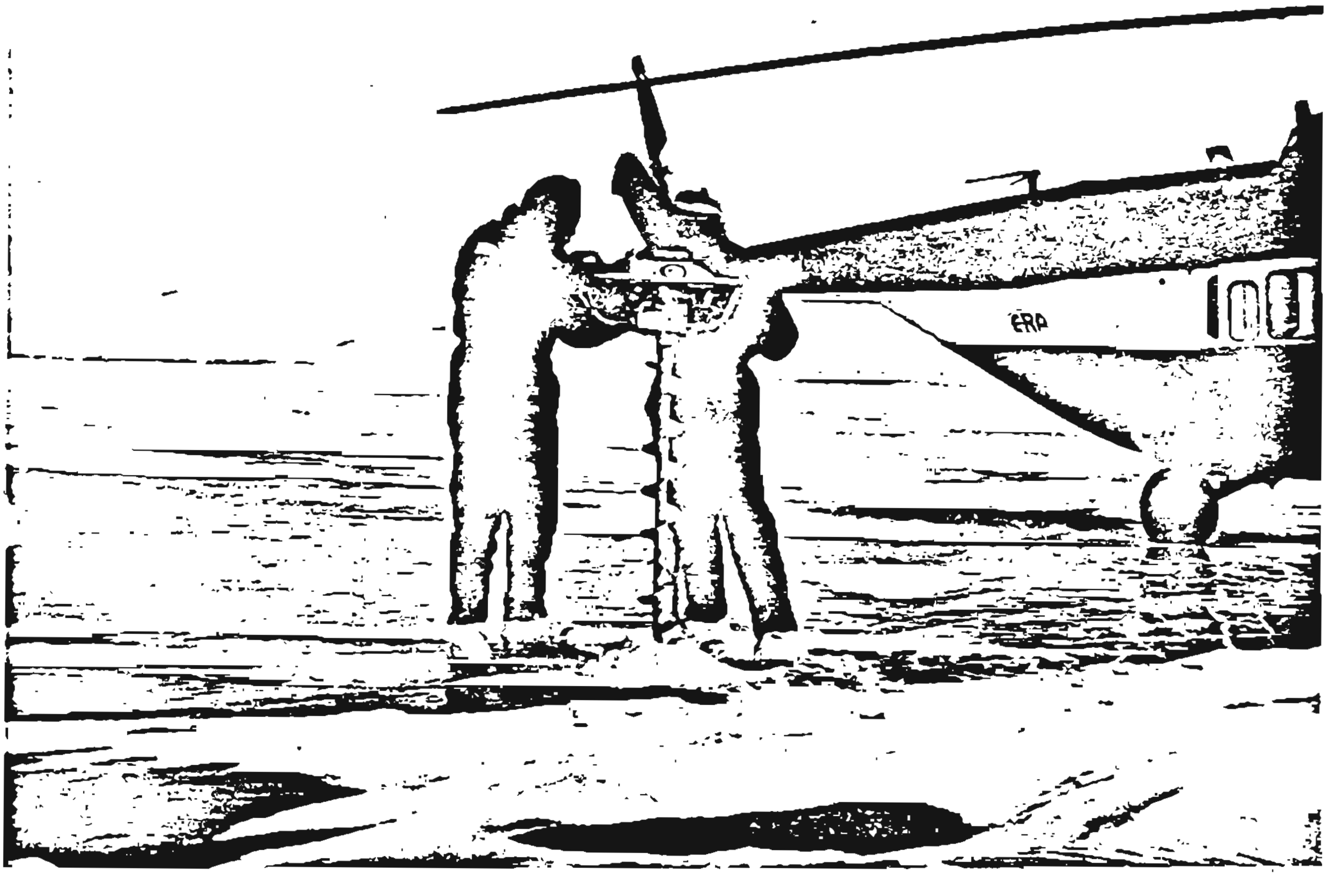
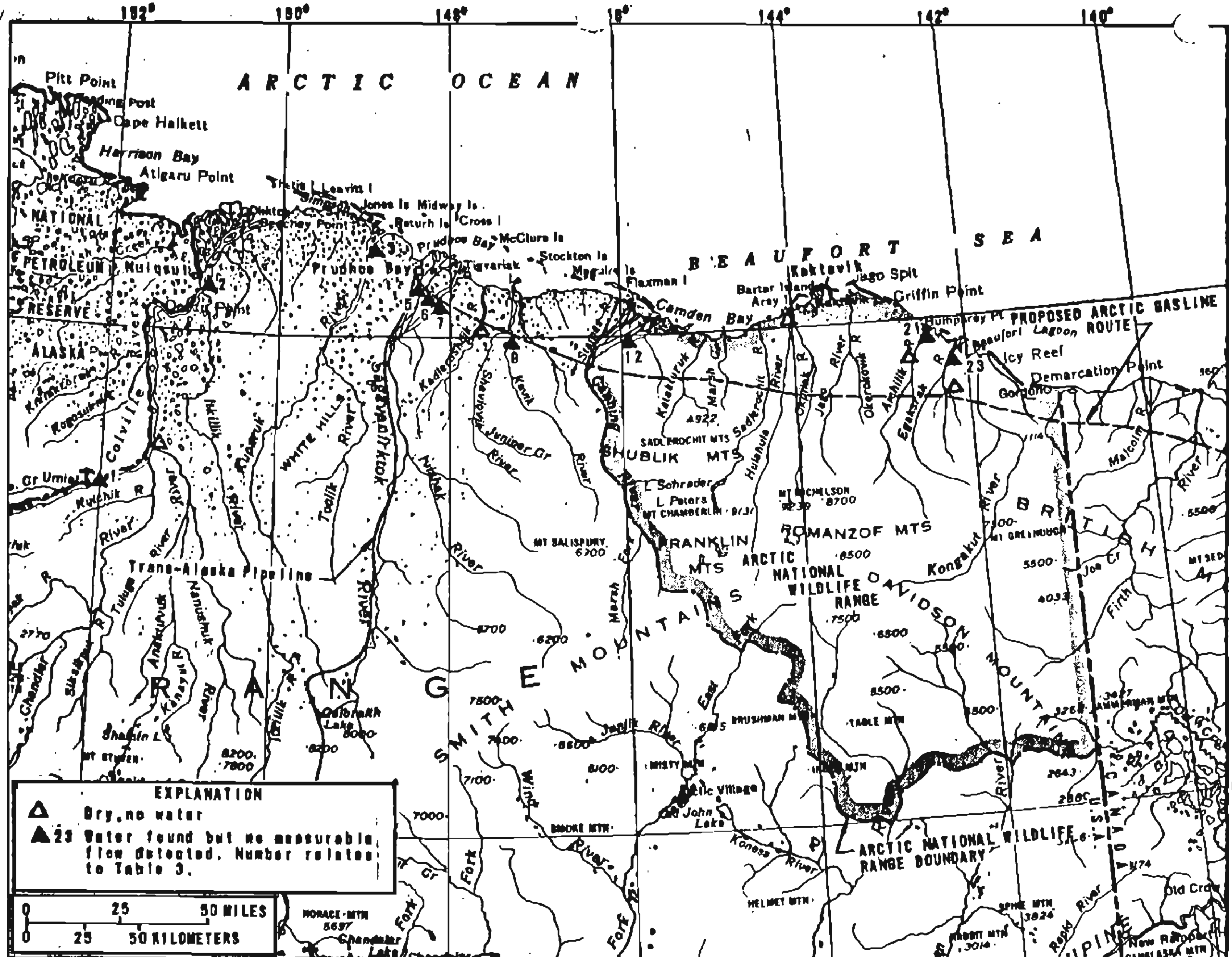
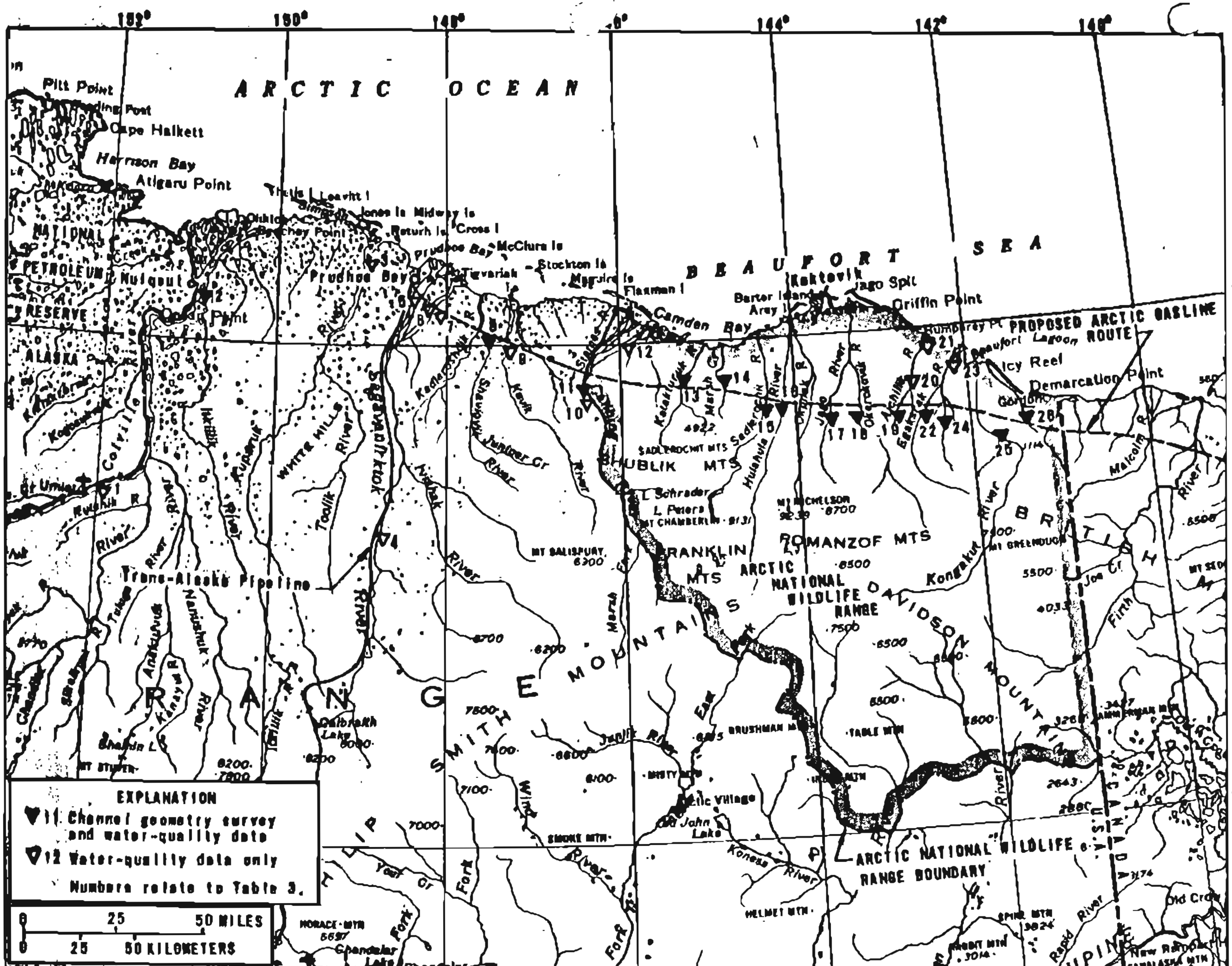


Fig. 24 - 100% Halftone



Base from U.S. Geological Survey Alaska map E

Figure 25.--Stream sites at which no measurable winter flow of water was found.



Base from U.S. Geological Survey Alaska map E

Figure 26.--Stream-sampling sites for water quality and channel geometry data.

Table 3.--*Dissolved chemical constituents and physical parameters for streams, eastern Arctic Slope (all constituents reported in mg/L unless otherwise specified).*

Map No. from fig. 26	1	2		3	4
Station name	Colville R nr Umiat	Colville R nr Nuiqsut		Kuparuk R nr Deadhorse	Sagavanirktok R nr Sagwon
Latitude	69°21'45"	70°09'56"		70°16'54"	68°05'15"
Longitude	152°05'40"	150°55'00"		148°57'35"	148°45'10"
Date	04-19-75	04-29-75	08-14-75	04-29-75	04-20-75
Time	16:30	09:30	12:15	11:30	12:00
Discharge (ft^3/s)	0	0	12,700	0	1.2
Silica	3.3	4.0	2.1	4.4	2.7
Iron (µg/L)	--	--	20	--	--
Manganese (µg/L)	--	--	0	--	--
Calcium	44*	117*	22	93*	62*
Magnesium	--	--	5.0	--	--
Sodium	3.9	160	2.5	4.6	3.5
Potassium	1.1	6.1	0.6	1.3	0.5
Bicarbonate	134	198	78	246	180
Carbonate	--	--	0	--	--
Alkalinity, total ($CaCO_3$)	--	--	64	--	--
Sulfate	23	65	9.5	4.8	12
Chloride	1.0	290	1.5	4.1	1.0
Fluoride	0.0	0.1	0.1	0.0	0.2
Nitrate and nitrite as N	0.55	0.29	0.09	0.01	0.19
Orthophosphorus as P	0.01	0.00	0.00	0.03	0.00
Dissolved solids (sum of determined constituents)	--	--	82	--	--
Hardness, total	110	292	76	--	156
Non-carbonate hardness	--	--	12	--	--
Specific conductance (micromhos/cm at 25°C)	238	1,520	160	426	310
pH (units)	6.9	7.5	8.1	7.5	8.0
Water temperature (°C)	0.0	1.0	10.0	0.0	0.5
Color (platinum-cobalt units)	0	0	10	0	0
Turbidity (Jackson Turbidity units)	2	2	1.5	--	1
Dissolved oxygen	3.6	14.4	11.3	1.4	6.7
Total organic carbon	4.2	5.7	3.6	16	--

*Calcium and magnesium (calculated as calcium)

Table 3.--*Dissolved chemical constituents and physical parameters for streams, eastern Arctic Slope (all constituents reported in mg/L unless otherwise specified).*

Map No. from fig. 26	5	6	7	8
Station name	Sagavanirktok R W Chnl nr Deadhorse	Sagavanirktok R W br of E Chnl	Sagavanirktok R E br of E Chnl	Shaviovik R
Latitude	70°12'16"	70°09'38"	70°09'22"	70°05'07"
Longitude	148°24'10"	148°10'43"	148°08'38"	147°16'30"
Date	11-11-75	11-11-75	11-11-75	08-13-75
Time	--	--	--	09:00
Discharge (ft^3/s)	0	0	0	E335
Silica	3.7	3.4	2.7	--
Iron (µg/L)	--	--	--	--
Manganese (µg/L)	--	--	--	--
Calcium	--	--	--	81*
Magnesium	--	--	--	--
Sodium	2.1	0.9	1.2	--
Potassium	0.2	0.1	0.2	--
Bicarbonate	257	126	114	110
Carbonate	--	--	--	--
Alkalinity, total ($CaCO_3$)	--	--	--	--
Sulfate	30	17	25	--
Chloride	3.2	0.8	1.4	--
Fluoride	--	--	--	--
Nitrate and nitrite as N	0.24	0.16	0.21	--
Orthophosphorus as P	0.00	0.00	0.00	0.
Dissolved solids (sum of determined constituents)	--	--	--	--
Hardness, total	--	--	--	--
Non-carbonate hardness	--	--	--	--
Specific conductance (micromhos/cm at 25°C)	400	--	330	235
pH (units)	7.7	7.7	6.8	7.6
Water temperature (°C)	0.0	0.0	0.0	8.0
Color (platinum-cobalt units)	--	--	--	5
Turbidity (Jackson Turbidity units)	--	--	--	.25
Dissolved oxygen	--	--	--	12
Total organic carbon	5.5	--	--	4.2

*Calcium and magnesium (calculated as calcium)

Table 3.--*Dissolved chemical constituents and physical parameters for streams, eastern Arctic Slope (all constituents reported in mg/L unless otherwise specified).*

Map No. from fig. 26	9	10	11	12	13	14
Station name	Kavik R nr Deadhorse	Canning R nr Kaktovik	Canning R	Canning R delta E Chnl	Katakturuk R	Marsh Cr
Latitude	70°01'50"	69°48'29"	69°50'38"	70°04'38"	69°52'25"	69°47'33"
Longitude	147°18'05"	146°23'25"	146°27'10"	145°42'35"	145°12'00"	144°49'00"
Date	08-13-75	11-08-75	08-12-75	11-30-75	08-10-75	08-10-75
Time	--	--	16:00	--	09:30	12:30
Discharge (ft^3/s)	0	228	E2500	0	E400	E15
Silica	2.5	2.6	--	2.3	--	--
Iron (µg/L)	--	--	--	--	--	--
Manganese (µg/L)	--	--	--	--	--	--
Calcium	--	--	--	--	--	--
Magnesium	--	--	--	--	--	--
Sodium	1.8	1.8	--	1.4	--	--
Potassium	0.4	0.2	--	0.3	--	--
Bicarbonate	165	162	107	123	120	112
Carbonate	--	--	--	--	--	--
Alkalinity, total ($CaCO_3$)	--	--	--	--	--	--
Sulfate	28	31	--	34	--	--
Chloride	1.6	1.3	--	0.9	--	--
Fluoride	--	--	--	--	--	--
Nitrate and nitrite as N	0.18	0.12	--	0.15	--	--
Orthophosphorus as P	0.01	0.00	--	0.01	--	--
Dissolved solids (sum of determined constituents)	--	--	--	--	--	--
Hardness, total	--	--	--	--	--	--
Non-carbonate hardness	--	--	--	--	--	--
Specific conductance (micromhos/cm at 25°C)	390	320	240	--	250	425
pH (units)	7.2	7.7	7.7	6.7	7.8	7.5
Water temperature (°C)	0.0	0.0	9.0	0.0	3.0	3.5
Color (platinum-cobalt units)	--	--	5	--	5	5
Turbidity (Jackson Turbidity units)	--	--	1.3	--	20	2
Dissolved oxygen	--	--	11.8	--	13.2	12.2
Total organic carbon	--	--	27	8.9	3.7	6.0

Table 3.--*Dissolved chemical constituents and physical parameters for streams, eastern Arctic Slope (all constituents reported in mg/L unle otherwise specified).*

Map No. from fig. 26	15	16	17	18	19	20
Station name	Sadlerochit R nr Kaktovik	Hulahula R	Jago R	Okerokovik R	Aichilik R	Aichilik R site 2 nr Kaktovik
Latitude	69°39'13"	69°41'47"	69°50'38"	69°42'07"	69°35'23"	69°40'30"
Longitude	144°22'56"	144°12'10"	146°27'10"	143°14'23"	142°58'03"	142°46'52"
Date	08-07-75	08-07-75	08-08-75	08-08-75	08-11-75	11-25-75
Time	16:00	09:30	09:00	14:00	09:30	--
Discharge (ft^3/s)	--	739	267	85.2	E800	0
Silica	--	--	--	--	--	3.0
Iron (µg/L)	--	--	--	--	--	--
Manganese (µg/L)	--	--	--	--	--	--
Calcium	--	--	--	--	--	--
Magnesium	--	--	--	--	--	--
Sodium	--	--	--	--	--	1.6
Potassium	--	--	--	--	--	0.5
Bicarbonate	50	76	70	123	96	180
Carbonate	--	--	--	--	--	--
Alkalinity, total ($CaCO_3$)	--	--	--	--	--	--
Sulfate	--	--	--	--	--	45
Chloride	--	--	--	--	--	0.9
Fluoride	--	--	--	--	--	--
Nitrate and nitrite as N	--	--	--	--	--	0.19
Orthophosphorus as P	--	--	--	--	--	0.24
Dissolved solids (sum of determined constituents)	--	--	--	--	--	--
Hardness, total	--	--	--	--	--	--
Non-carbonate hardness	--	--	--	--	--	--
Specific conductance (micromhos/cm at 25°C)	155	210	193	275	235	370
pH (units)	7.1	7.5	7.7	7.5	7.5	7.2
Water temperature (°C)	7.0	4.0	4.5	8.0	3.5	0.0
Color (platinum-cobalt units)	--	5	5	5.0	5	--
Turbidity (Jackson Turbidity units)	0.25	2	1	0.0	1	--
Dissolved oxygen	11.6	12.9	12.8	11.6	12.9	--
Total organic carbon	3.8	5.7	6.6	14	1.8	--

Table 3.--*Dissolved chemical constituents and physical parameters for streams, eastern Arctic Slope (all constituents reported in mg/L unless otherwise specified).*

Map No. from fig. 26	21	22	23	24	25	26
Station name	Aichilik R nr mouth	Egaksrak R	Egaksrak R nr mouth	Ekaluakat R	Kongakut R	Turner R
Latitude	69°48'50"	69°32'05"	69°48'47"	69°34'35"	69°30'54"	69°35'56"
Longitude	142°10'00"	142°41'05"	142°05'23"	142°18'38"	141°42'34"	141°24'10"
Date	11-23-75	08-11-75	11-23-75	08-09-75	08-09-75	08-09-75
Time	--	12:00	--	16:00	09:00	13:30
Discharge (ft^3/s)	0	E500	0	101	E2000	227
Silica	5.5	--	5.0	--	--	--
Iron (µg/L)	--	--	--	--	--	--
Manganese (µg/L)	--	--	--	--	--	--
Calcium	--	--	--	--	--	--
Magnesium	--	--	--	--	--	--
Sodium	4.2	--	15	--	--	--
Potassium	0.6	--	0.7	--	--	--
Bicarbonate	296	84	139	146	110	150
Carbonate	--	--	--	--	--	--
Alkalinity, total ($CaCO_3$)	--	--	--	--	--	--
Sulfate	84	--	41	--	--	--
Chloride	5.1	--	23	--	--	--
Fluoride	--	--	--	--	--	--
Nitrate and nitrite as N	0.37	--	0.40	--	--	--
Orthophosphorus as P	0.00	--	0.00	--	--	--
Dissolved solids (sum of determined constituents)	--	--	--	--	--	--
Hardness, total	--	--	--	--	--	--
Non-carbonate hardness	--	--	--	--	--	--
Specific conductance (micromhos/cm at 25°C)	700	175	--	325	250	305
pH (units)	7.2	7.5	6.8	7.7	7.7	7.6
Water temperature (°C)	0.0	5.5	0.0	6.5	6.5	6.5
Color (platinum-cobalt units)	--	5	--	5	5	10
Turbidity (Jackson Turbidity units)	--	0	--	1	1	0
Dissolved oxygen	--	12.2	--	11.6	11.9	11.7
Total organic carbon	--	7.9	--	1.8	2.4	6.7

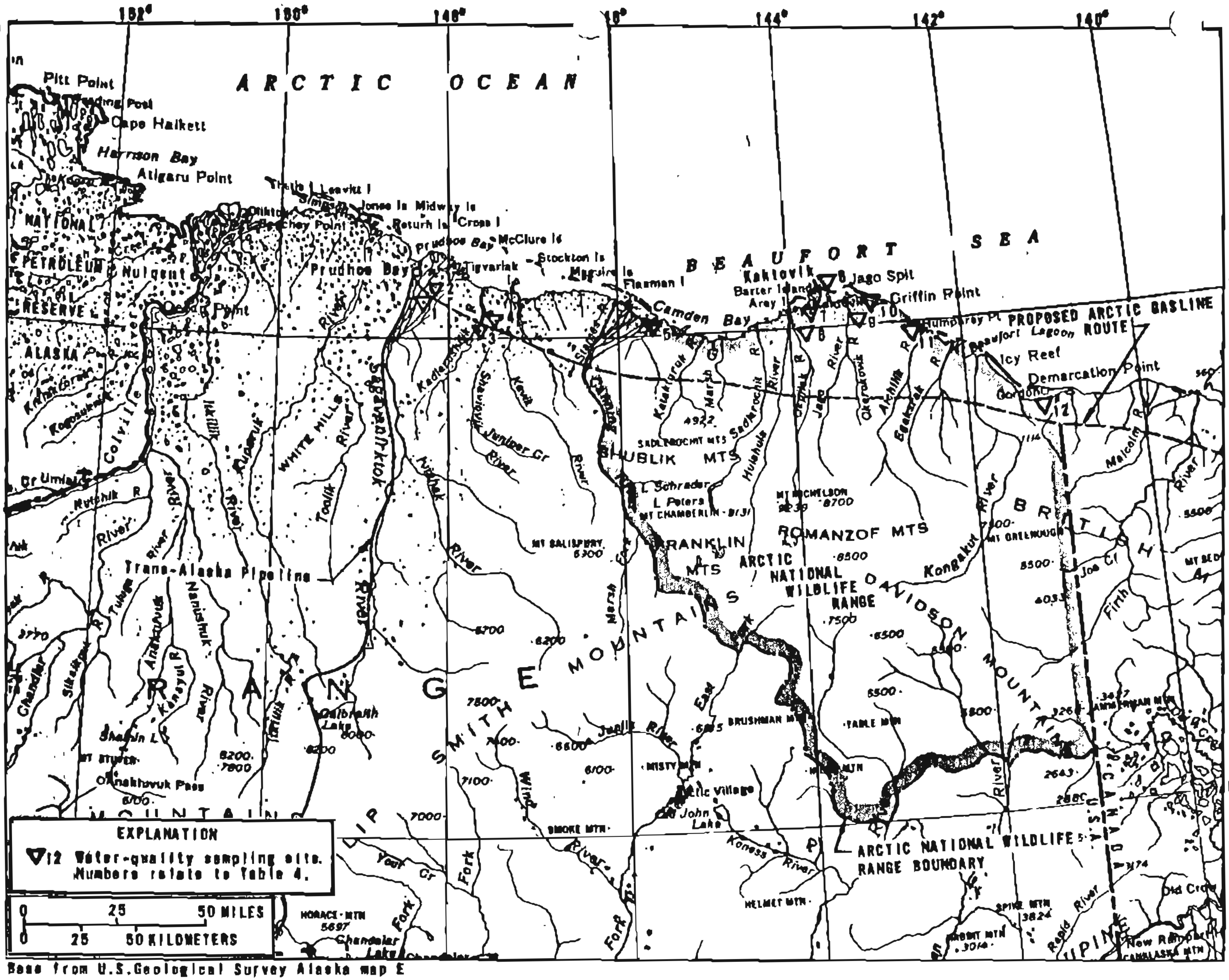


Figure 27.--Location of lakes sampled for water quality.

Table 4.--*Dissolved chemical constituents and physical parameters for lakes, eastern Arctic Slope (all constituents reported in mg/L unless otherwise specified).*

Map No. from fig. 27	1		2	3	4
Station name	Unnamed Lake nr Deadhorse		Unnamed Lake nr Deadhorse	Unnamed Lake nr Kadlerochilik R	Unnamed Lake nr Kadlerochilik R
Latitude	70°11'00"		70°12'30"	70°04'30"	70°06'10"
Longitude	148°12'46"		148°10'30"	147°42'10"	147°30'50"
Date	08-13-75	11-10-75	11-08-75	11-10-75	11-10-75
Time	11:30	--	--	--	--
Water depth	1.6	--	4.0	2.2	2.5
Ice thickness	2.2	--	1.5	2.6	2.5
Silica	0.3	0.2	0.0	0.0	0.0
Iron (µg/L)	20	--	--	--	--
Manganese (µg/L)	0	--	--	--	--
Calcium	40	--	--	--	--
Magnesium	3.5	--	--	--	--
Sodium	9.9	23	28	11	8.2
Potassium	1.0	1.7	0.9	0.6	0.2
Bicarbonate	113	122	102	125	80
Carbonate	0	--	--	--	--
Alkalinity, total ($CaCO_3$)	84	--	--	--	--
Sulfate	1.1	3.6	5.1	2.4	2.4
Chloride	26	64	85	69	68
Fluoride	0.1	--	--	--	--
Nitrate and nitrite as N	0.02	0.08	0.07	0.04	0.07
Orthophosphorus as P	0.00	0.04	0.02	0.01	0.01
Dissolved solids (sum of determined constituents)	132	--	--	--	--
Hardness, total	110	--	--	--	--
Non-carbonate hardness	31	--	--	--	--
Specific conductance (micromhos/cm at 25°C)	275	--	--	510	372
pH (units)	7.6	6.7	6.8	6.7	7.5
Water temperature (°C)	9.0	0.0	0.0	0.0	0.0
Color (platinum-cobalt units)	15	--	--	--	--
Turbidity (Jackson Turbidity units)	3.5	--	--	--	--
Dissolved oxygen	11.4	--	--	--	--
Total organic carbon	9.4	8.5	--	--	--

Table 4.--*Dissolved chemical constituents and physical parameters for lakes, eastern Arctic Slope (all constituents reported in mg/L unle otherwise specified).*

Map No. from fig. 27	5	6	7	8	
Station name	Unnamed Lake nr Canning R Delta	Unnamed Lake nr Kaktovik	Unnamed Lake nr Kaktovik	Barter Island Lake	
Latitude	70°01'37"	69°59'55"	70°03'13"	70°07'15"	
Longitude	145°31'26"	143°43'51"	143°43'51"	143°38'18"	
Date	11-30-75	11-22-75	11-25-75	08-18-72	04-27-75
Time	11:30				22:00
Water depth	3.5	2.6	3.0	--	0.5
Ice thickness	3.8	3.6	3.2	--	6.0
Silica	0.0	0.0	0.0	2.1	0.0
Iron (μg/L)	--	--	--	.01	--
Manganese (μg/L)	--	--	--	.00	--
Calcium	--	--	--	35	--
Magnesium	--	--	--	13	--
Sodium	4.7	5.0	3.7	46	800
Potassium	0.2	0.6	0.2	2.1	15
Bicarbonate	44	53	26	97	--
Carbonate	--	--	--	--	--
Alkalinity, total ($CaCO_3$)	--	--	--	--	--
Sulfate	1.8	2.6	1.8	3.1	16
Chloride	11	11	8.9	120	1600
Fluoride	--	--	--	0.1	0.3
Nitrate and nitrite as N	.06	0.06	0.00	0.02	0.03
Orthophosphorus as P	0.02	0.01	0.09	--	0.07
Dissolved solids (sum of determined constituents)	--	--	--	270	--
Hardness, total	--	--	--	140	--
Non-carbonate hardness	--	--	--	61	--
Specific conductance (micromhos/cm at 25°C)	106	115	96	543	7,130
pH (units)	7.1	7.4	7.1	7.0	7.3
Water temperature (°C)	0.0	0.0	0.0	--	--
Color (platinum-cobalt units)	--	--	--	--	--
Turbidity (Jackson Turbidity units)	--	--	--	--	--
Dissolved oxygen	--	--	--	--	--
Total organic carbon	--	--	--	40	--

*Calcium & Magnesium (calculated as carbon)

Table 4.--*Dissolved chemical constituents and physical parameters for lakes, eastern Arctic Slope (all constituents reported in mg/L unless otherwise specified).*

Map No. from fig. 27	9	10	11	12
Station name	Unnamed Lake nr Jago R	Unnamed Lake nr Jago R	Unnamed Lake nr Aichilik	Unnamed Lake nr Demarcation Point
Latitude	70°02'10"	70°04'50"	69°49'50"	69°38'10"
Longitude	143°13'40"	143°10'00"	142°07'15"	141°04'30"
Date	11-17-75	11-17-75	11-24-75	11-18-75
Time	--	--	--	--
Water depth	4.8	7.2	7.3	4.2
Ice thickness	2.7	2.8	3.4	2.8
Silica	0.0	0.3	0.1	0.0
Iron (µg/L)	--	--	--	--
Manganese (µg/L)	--	--	--	--
Calcium	--	--	--	--
Magnesium	--	--	--	--
Sodium	5.4	16	35	3.5
Potassium	0.8	0.4	1.2	0.1
Bicarbonate	32	29	147	69
Carbonate	--	--	--	--
Alkalinity, total ($CaCO_3$)	--	--	--	--
Sulfate	1.3	2.0	1.8	1.8
Chloride	11	57	69	6.9
Fluoride	--	--	--	--
Nitrate and nitrite as N	0.04	0.09	0.02	0.02
Orthophosphorus as P	0.02	0.01	0.01	0.00
Dissolved solids (sum of determined constituents)	--	--	--	--
Hardness, total	--	--	--	--
Non-carbonate hardness	--	--	--	--
Specific conductance (micromhos/cm at 25°C)	80	280	--	170
pH (units)	6.9	7.1	6.8	7.6
Water temperature (°C)	0.0	0.0	0.0	0.0
Color (platinum-cobalt units)	--	--	--	--
Turbidity (Jackson Turbidity units)	--	--	--	--
Dissolved oxygen	--	--	--	--
Total organic carbon	--	--	--	--

dissolved chloride and 800 mg/L of dissolved sodium. Total organic carbon was measured at 40 mg/L. A sample taken on August 18, 1972, from the lake on Barter Island had a specific conductance of 543 micromhos and contained 120 mg/L of dissolved chloride and 46 mg/L of dissolved sodium.

Lakes near the coast tend to have higher sodium and chloride concentrations than lakes farther inland, presumably because of aerosols derived from the nearby Beaufort Sea.

AQUATIC INVERTEBRATES

Aquatic invertebrates were collected during April and August 1975 trips, but no collections were made during the November 1975 trip.

Biological sampling was conducted at 8 spring sites during the April trip. Ten-rock samples were collected from all springs except Red Hill springs where only a 2-rock sample was collected because of the abundance of organisms present. Drift net samples were obtained from the Katakturuk River tributary spring and Kongakut River spring along the delta.

During the August trip, 2 springs and 10 stream sites were sampled. Drift net samples were taken at all sites, except for Sadlerochit Spring. Surber samples were collected from Sadlerochit Spring and the Ekaluakat River.

Five Surber samples from Sadlerochit Spring and four from the Ekaluakat River were collected. Each sample was collected from a different area, thus making up a diverse set of samples for the site; the data was then arranged for the site.

Each rock sample consisted of 10 rocks ranging from about 6 to 12 in (150 to 300 mm) in diameter collected at random in the vicinity of the spring source. The method of collection of organisms from rocks is described in Nauman and Kernodle (1974).

Drift-net samples were taken with a modified Surber stream-bottom sampler used as a drift net. Use of the Surber sampler is described by Slack and others (1973). A drift net site in the Ekaluakat icing is shown in figure 28. A 1-hour drift-net collection was obtained from an area of swift flow at each of the stream sites sampled. The drift net, made of nylon screen cloth netting with a 210-μ mesh, had a 12x12-in (305 x 305-mm) opening which was held perpendicular to the current by rods driven into the streambed. The bottom of the net frame was in contact with the streambed and the top extended above the water surface in order to collect the surface film. Drift-net samples do not collect all the taxa present; however, this method has proven to be a useful tool for comparing biological communities in streams. It should be noted that not all streams visited were sampled for aquatic invertebrates.

The samples collected from the Kongakut River, Egaksrak River, Sadlerochit Spring, and Red Hill spring contained greater numbers of aquatic invertebrates and more taxa (table 5) than the other sites sampled. Diptera (two-winged insects), mostly Chironomidae (midges), were the most abundant aquatic invertebrates collected, comprising from 10 to 100 percent of the samples (table 5). Red Hill spring had the

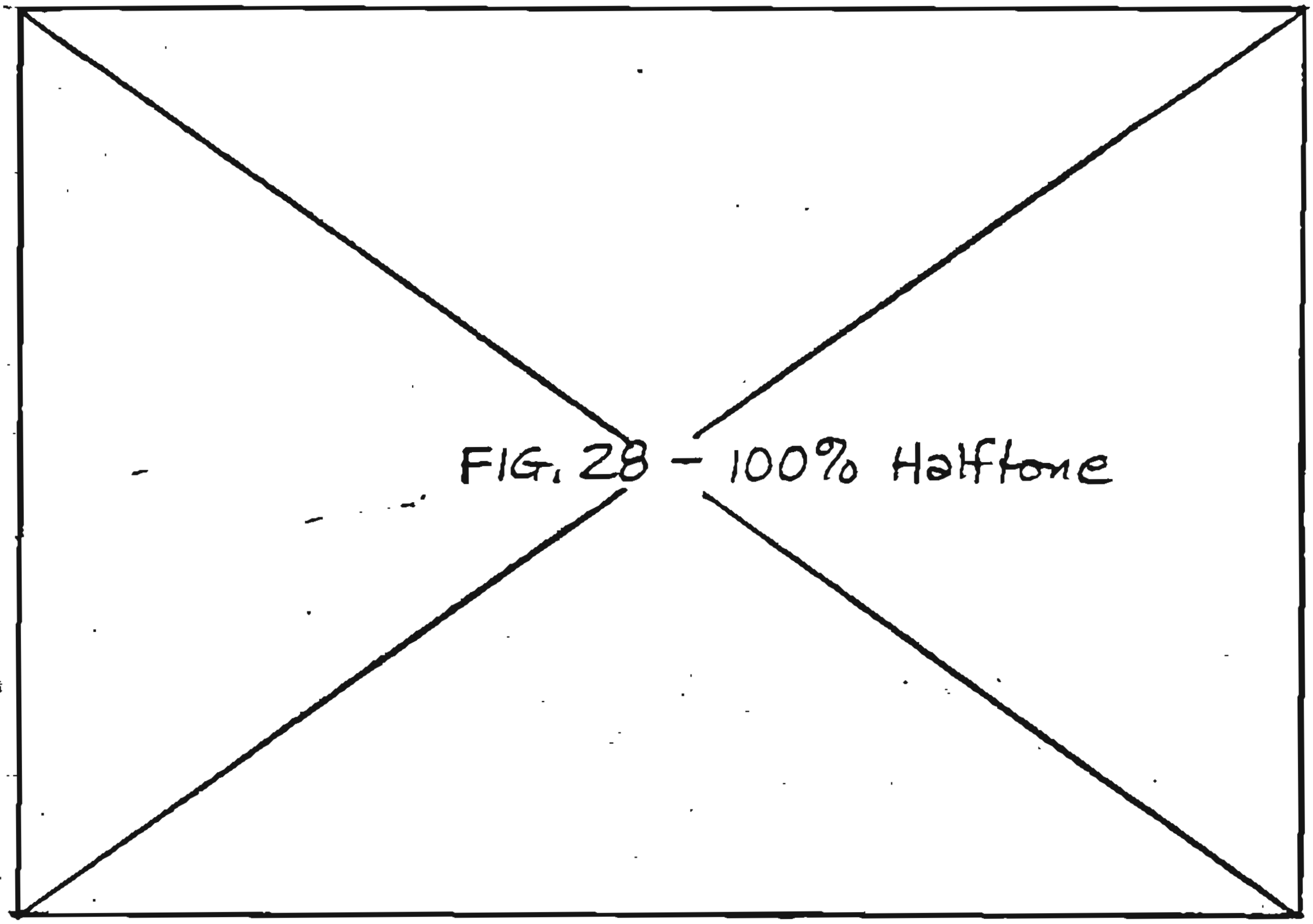


Figure 28.-- Biological-sampling site in Ekaluakat icing, July 1975.

Fig. 28 - 100% Halftone

Table 5a.--*Occurrence of aquatic invertebrates in percent of sample at each spring site.* P = present but constituting less than 1 percent of sample

Map No. from fig. 20	4	8		9		10	
Station name	Flood Creek spring	Red Hill spring		Katakturuk R trib. spring		Sadlerochit spring	
Collection date	4/20/75	4/28/75	8/12/75	4/22/75	4/22/75	4/27/75	8/7/75
Sample type	10-rock	2-rock	drift	10-rock	drift	10-rock	*Surber
Worms:							
Nematoda - round worms	74	--	P	P	--	1	1
Oligochaeta - aquatic worms	3	--	P	P	2	2	2
Turbellaria - flat worms	P	--	--	--	--	P	P
Crustacea:							
Amphipoda - fairy shrimp	--	--	1	--	--	1	3
Cladocera - water fleas	--	--	10	--	--	--	--
Copepoda - copepods	3	--	2	--	--	P	2
Ostracoda - seed shrimp	2	--	--	--	--	--	18
Mollusca:							
Gastropoda - snails	--	--	--	--	--	1	P
Pelecypoda - clams	--	--	--	--	--	--	15
Immature Insecta:							
Diptera - two-winged insects	--	--	--	--	--	--	--
Anthomyiidae - anthomyiids	--	--	--	--	--	--	P
Chironomidae - midges	10	>99	81	89	95	81	50
Empidae - dance flies	--	--	P	--	--	--	P
Ephydridae - Shore flies			P				
Phoridae - hump-backed flies	--	--	--	--	--	--	--
Simuliidae - black flies	--	--	--	P	--	--	P
Syrphidae - flower flies	--	--	P	--	--	--	--
Psychodidae - moth flies	--	--	P	--	--	P	P
Tipulidae - crane flies	--	P	P	P	1	1	P
Ephemeroptera - mayflies	--	--	2	4	1	P	1
Plecoptera - stoneflies	6	--	--	P	--	8	3
Trichoptera - caddisflies	1	--	--	5	--	4	3
Miscellaneous organisms:							
Coleoptera - beetles	--	--	P	--	--	--	P
Collembola - springtails	1	--	P	--	--	--	P
Acarina - mites	P	--	1	--	--	P	1
Total aquatic invertebrates collected	854	6,569	10,456	1,496	225	3,620	1,629
Number of taxa collected per sample	10	2	15	8	4	13	20
Total taxa collected per station	10		15		8		20

*Average of 5 Surber samples

able 5a.--*Occurrence of aquatic invertebrates in percent of sample at each spring site.* P= present but constituting less than 1 percent of sam

Map No. from fig. 20	11	13	14	16	
Station name	Hulahula R spring	Aichilik R spring	Ekaluakat R. spring	Kongakut River spring above delta	
Collection date	4/28/75	4/27/75	4/22/75	4/27/75	4/27/75
Sample type	10-rock	10-rock	10-rock	10-rock	drift
Worms:					
Nematoda - round worms	--	--	6	--	--
Oligochaeta - aquatic worms	--	--	1	P	2
Turbellaria - flat worms	--	--	--	--	--
Crustacea:					
Amphipoda - fairy shrimp	--	--	5	--	--
Cladocera - water fleas	--	--	--	--	--
Copepoda - copepods	--	--	15	--	--
Ostracoda - seed shrimp	--	--	5	--	--
Mollusca:				--	--
Gastropoda - snails	--	--	--	--	--
Pelecypoda - clams	--	--	--	--	--
Immature Insecta:					
Diptera - two-winged insects	--	--	--	--	--
Anthomyiidae - anthomyiids	--	--	--	--	--
Chironomidae - midges	95	95	58	99	95
Empidae - dance flies	--	--	--	--	--
Phoridae - hump-backed flies	--	--	--	--	--
Simuliidae - black flies	--	--	--	--	--
Syrphidae - flower flies	--	--	--	--	--
Psychodidae - moth flies	--	--	--	--	--
Tipulidae - crane flies	--	--	P	P	1
Ephemeroptera - mayflies	2	4	6	--	1
Plecoptera - stoneflies	3	1	3	--	--
Trichoptera - caddisflies	--	--	P	P	--
Miscellaneous organisms:					
Coleoptera - beetles	--	--	--	--	--
Collembola - springtails	--	--	--	--	--
Acarina - mites	--	--	P	--	--
Total aquatic invertebrates collected	1,199	1,098	649	1,872	225
Number of taxa collected per sample	3	3	11	5	4
Total taxa collected per station					

able 5b.--Occurrence of aquatic invertebrates in percent of sample at each stream site. P = present but constituting less than 1 percent of sample

Map No. (from fig. 26)	8	11	13	14	16	17	18
Station name	Shaviovik River	Canning River	Katakturuk River	Marsh Creek	Hulahula River	Jago River	Okerokovik River
Collection date	8/13/75	8/12/75	8/10/75	8/10/75	8/7/75	8/8/75	8/8/75
Sample type	drift	drift	drift	drift	drift	drift	drift
Worms:							
Nematoda - round worms	--	--	--	--	--	P	--
Oligochaeta - aquatic worms	--	--	1	P	P	5	3
Turbellaria - flat worms	--	--	--	--	P	P	--
Crustacea:							
Amphipoda - fairy shrimp	--	--	--	--	--	--	8
Cladocera - water fleas	1	--	--	--	--	--	--
Copepoda - copepods	15	3	6	2	P	1	3
Ostracoda - seed shrimp	--	--	P	P	--	--	P
Mollusca:							
Gastropoda - snails	--	--	--	--	P	P	--
Pelecypoda - clams	--	--	--	--	--	--	--
Immature Insecta:							
Diptera - two-winged insects	--	--	--	--	--	--	--
Anthomyiidae - anthomyiids	--	--	--	--	--	--	--
Chironomidae - midges	41	90	20	41	67	53	32
Empidae - dance flies	--	--	2	P	P	2	P
Phoridae - hump-backed flies	--	--	--	--	--	--	--
Simulidae - black flies	P	P	4	--	22	19	1
Syrphidae - flower flies	--	--	--	--	--	--	--
Psychodidae - moth flies	--	--	--	P	--	--	--
Tipulidae - crane flies	2	4	1	3	P	--	3
Ephemeroptera - mayflies	10	1	32	36	5	8	7
Plecoptera - stoneflies	8	--	28	16	2	10	31
Trichoptera - caddisflies	P	--	--	--	--	--	--
Miscellaneous organisms:							
Coleoptera - beetles	P	--	P	P	--	--	P
Collembola - springtails	1	--	1	1	P	P	P
Acarina - mites	22	1	4	1	2	1	10
Total aquatic invertebrates collected	1,036	301	836	4,445	2,431	835	708
Number of taxa collected per sample	12	6	12	12	12	12	13
Total taxa collected per site							

aute 3b.--Occurrence of aquatic invertebrates in percent of sample at each stream site. P = present but constit-ting less than 1 percent of s ole

Map No. (from fig. 26)	19	22	24		25	26
Station name	Aichilik River	Egaksrak River	Ekaluakat River		Kongakut River	Turner River
Collection date	8/11/75	8/11/75	8/9/75	8/9/75	8/9/75	8/9/75
Sample type	drift	drift	drift	**Surber	drift	drift
Worms:						
Nematoda - round worms	P	1	--	P	P	4
Oligochaeta - aquatic worms	3	1	4	40	--	--
Turbellaria - flat worms	--	P	--	--	--	--
Crustacea:						
Amphipoda - fairy shrimp	--	P	P	--	P	1
Cladocera - water fleas	P	P	--	--	--	--
Copepoda - copepods	1	2	2	--	--	3
Ostracoda - seed shrimp	--	P	--	3	1	2
Mollusca:						
Gastropoda - snails	--	--	--	--	--	--
Pelecypoda - clams	--	--	--	--	--	--
Immature Insecta:						
Diptera - two-winged insects	--	--	--	--	--	--
Anthomyiidae - anthomyiids	--	--	--	--	--	--
Chironomidae - midges	85	86	64	51	83	44
Empidae - dance flies	P	P	--	P	P	--
Phoridae - hump-backed flies	--	--	--	--	P	--
Simuliidae - black flies	P	P	P	P	1	P
Syrphidae - flower flies	--	--	--	--	--	--
Psychodidae - moth flies	--	--	--	--	--	--
Tipulidae - crane flies	P	1	1	P	P	P
Ephemeroptera - mayflies	4	1	6	4	5	7
Plecoptera - stoneflies	4	5	16	1	6	36
Trichoptera - caddisflies	--	--	--	--	--	--
Miscellaneous organisms:						
Coleoptera - beetles	--	--	--	--	P	--
Collembola - springtails	P	1	P	1	P	P
Acarina - mites	1	1	6	P	2	3
Total aquatic invertebrates collected	997	815	804	501	2,038	1,046
Number of taxa collected per sample	12	15	10	11	13	11
Total taxa collected per site			13			

**average of 4 collected Surber samples

FIG. 29 - Halftone (120%)

Figure 29.-- Midge larvae in Red Hill Spring; scale is approximate.

Fig. 29 - Enlarge to 120% Halftone

greatest number of invertebrates, the sample consisting of almost 100 percent midges and less than 1 percent crane flies. It also had the greatest organism density; midges there numbered approximately 92,900/ft^2 (1,000,000/m^2) (fig. 29). Because of the large number of midges present, only 2 rocks, each approximately 10 in (254 mm) in diameter, were collected.

Red Hill Spring is unusual as it is a hot sulfur spring and only thermophilic algae are present near the water's source; however, aquatic invertebrates were collected approximately 600 ft (180 m) downstream where the individual small springs combine into a single main channel.

A photograph of a quiet pool at Saviukviayak tributary spring (fig. 30) indicates that aquatic invertebrate density may approach that of Red Hill spring. The aquatic invertebrate concentration at the Ekaluakat and Sadlerochit springs may be more representative of typical North Slope conditions. Organisms there numbered from 400 to 1,600/ft^2 (4,000 to 17,000/m^2), respectively.

Larger streams such as the Canning River are difficult to sample because of their size. The drift sample from the Canning River was collected in a shallow reach with slow flow; therefore, the six taxa collected may not be indicative of the drifting invertebrate populations in other parts of the river.

Although different methods of sampling were used during the two trips, it appears that total production and number of taxa were greater during summer. Furthermore, aquatic invertebrate production evidently is greater in springs with elevated water temperatures and with water that originates from bedrock.

Further sampling is needed in order to describe better the seasonal variation in aquatic invertebrate population; however, the samples collected provide a useful baseline for analyzing the aquatic invertebrate populations in the streams and springs sampled.

RECOMMENDATIONS FOR DATA COLLECTION SITES

The water resources of the Alaskan Arctic Slope are unique in the United States because of the climate and occurrence of continuous permafrost. The streams and perennial springs along the north flank of the Brooks Range are vital to the existing ecosystem and can be of significant value to man's use of the area. Construction on the fragile tundra vegetation poses an environmental problem. Permafrost decay caused by thermal alterations associated with construction or other activities can initiate erosion, the effects of which would be irreversible. This erosion would add sediment to the naturally low sediment load of the stream water. Further, the absence of flow during the long winters and the distribution of water in isolated pools beneath thick ice, place severe natural stresses on fish. Withdrawals of water or additions of polluted water to the limited receiving waters during winter could place intolerable stresses on and endanger the resident species. More information on the water resources of the North Slope is needed to assess the environmental impact of additional development. Monitoring of the water resources during man's use of the area may provide information useful in minimizing the impact.

FIG. 30 - Halftone @ 120%

Figure 30.-- Aquatic invertebrates at Saviukviayak tributary springs, April, 1975; scale is approximate.

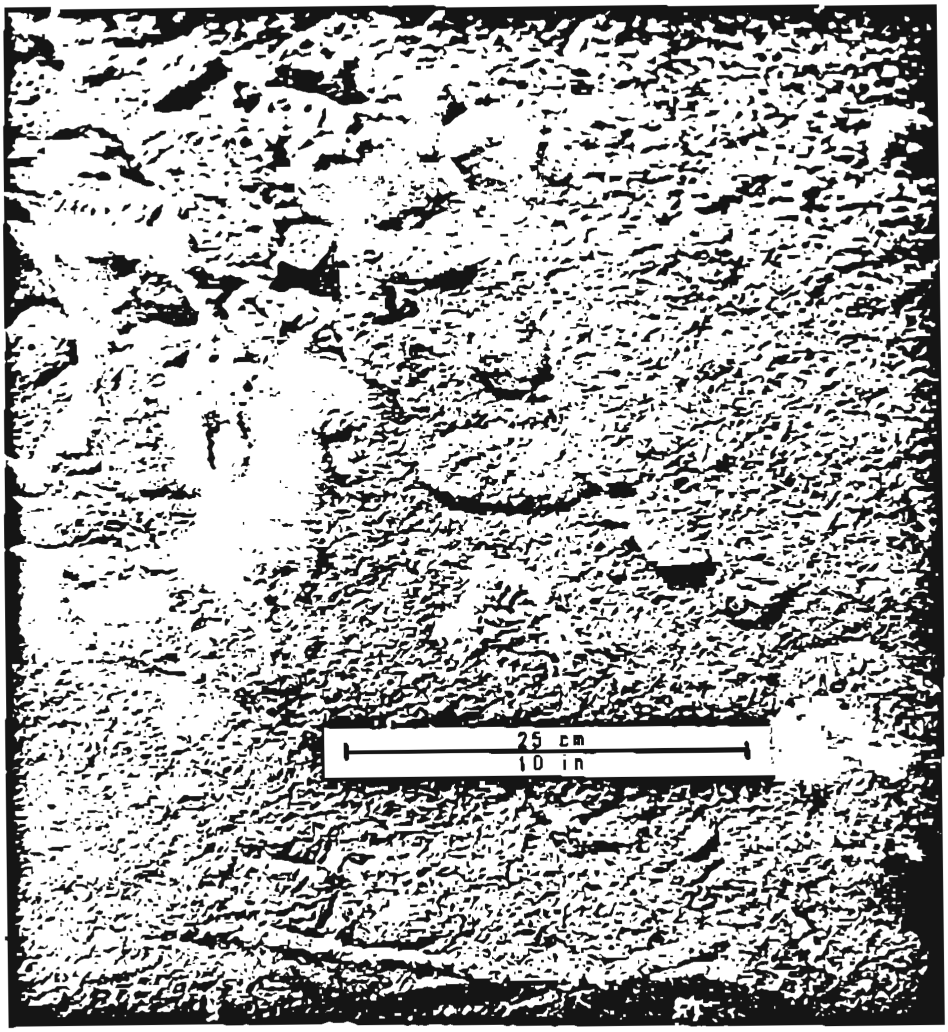


Fig. 30 - 120% enlargement halftone

Twelve principal streams with drainage areas exceeding 1,000 mi^2 (2,600 km^2) drain into the Beaufort Sea from Alaska. Of these, six are in this reconnaissance study area and two are now (1976) being gaged (the Kuparuk River near Deadhorse and the Sagavanirktok River near Sagwon). The Kuparuk River gage provides a hydrographic record for a large basin primarily on the Arctic Coastal Plain and foothills, whereas the Sagavanirktok River gage provides a record for a basin primarily in the Brooks Range and Arctic foothills. On the basis of these records, a comparison of runoff from the mountains and lowlands in large streams is possible.

The Colville and Canning Rivers are streams which form parts of the natural boundaries of National Petroleum Reserve Alaska and the Arctic National Wildlife Range, respectively. The hydrocarbon fuel resource of the Colville River area may be developed in the future. Because the Colville River is the largest stream in arctic Alaska and drains a basin wholly in the continuous permafrost zone, a gaging station near its mouth would provide valuable records for improving the inventory of water resources in this region.

Streams

Few reaches on the principal streams on the eastern Alaska Arctic Slope offer acceptable sites for continuous streamflow data collection. However, acceptable sites were found on the Canning River near the Shublik Mountains, on the Hulahula River in the foothills of the Brooks Range, and on the Colville River at the head of its delta (fig. 2).

At the site on the Canning River the water is confined to one channel by steep banks of bedrock. The reach consists of pools and riffles (fig. 31). The streambed is composed of loose cobbles and sand and is subject to shifting. Conditions for streamflow measurements and water-quality sampling are acceptable for the open-water season. This site was not visited during the winter, but it probably is in an area of active aufeis (icing) formation and has little or no flow under ice.

An acceptable site for data collection on the Hulahula River is near a fishing and hunting camp traditionally used by the Eskimos from Kaktovik (fig. 32). The left bank at this site is steep bedrock that forms nearly vertical walls. The right bank is a low, vegetated terrace. The stream flows in one channel. The bed material is large cobbles and angular rocks and probably subject to minor shifting. Streamflow measurement and sampling conditions are acceptable for summer and winter. An alternative data-collection site on the Hulahula River (fig. 9) is downstream from that shown in figure 32 and is at the flood survey site.

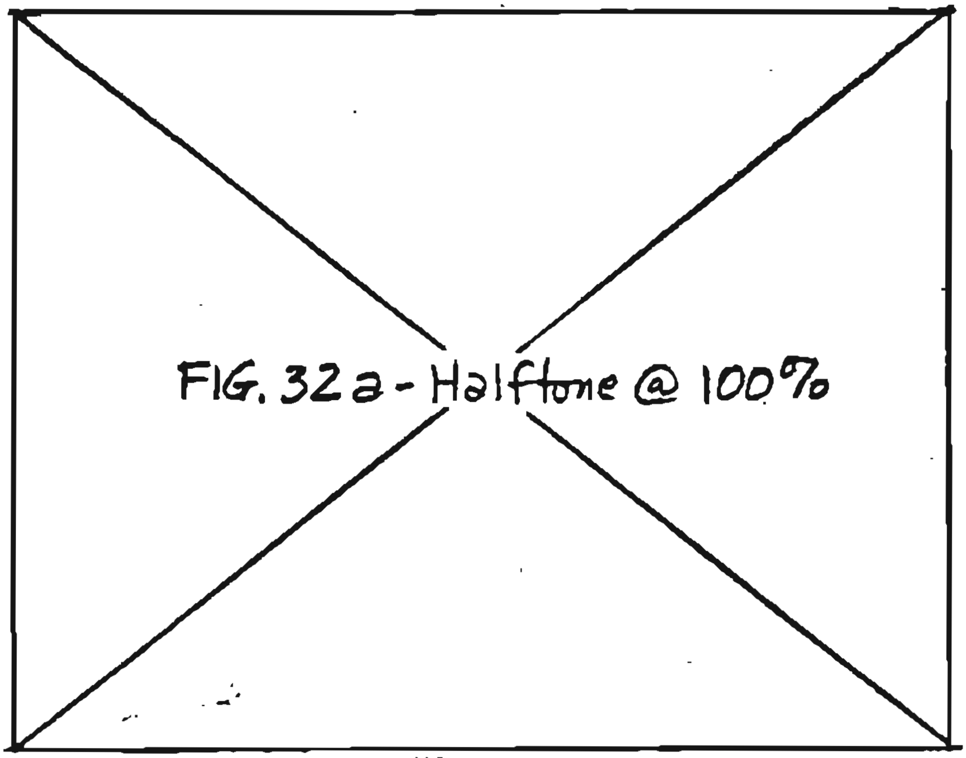
A gage at the recommended site on the Hulahula River would measure the runoff from an area on the north flank of the eastern Brooks Range. No part of its basin is on the coastal plain. The Hulahula River is an important stream for the production of Arctic char.

The Colville River at the head of the delta has a short, straight reach (fig. 33) confined to a single channel. The channel is fairly uniform and bed material consists of silt, sand, and small gravel. The

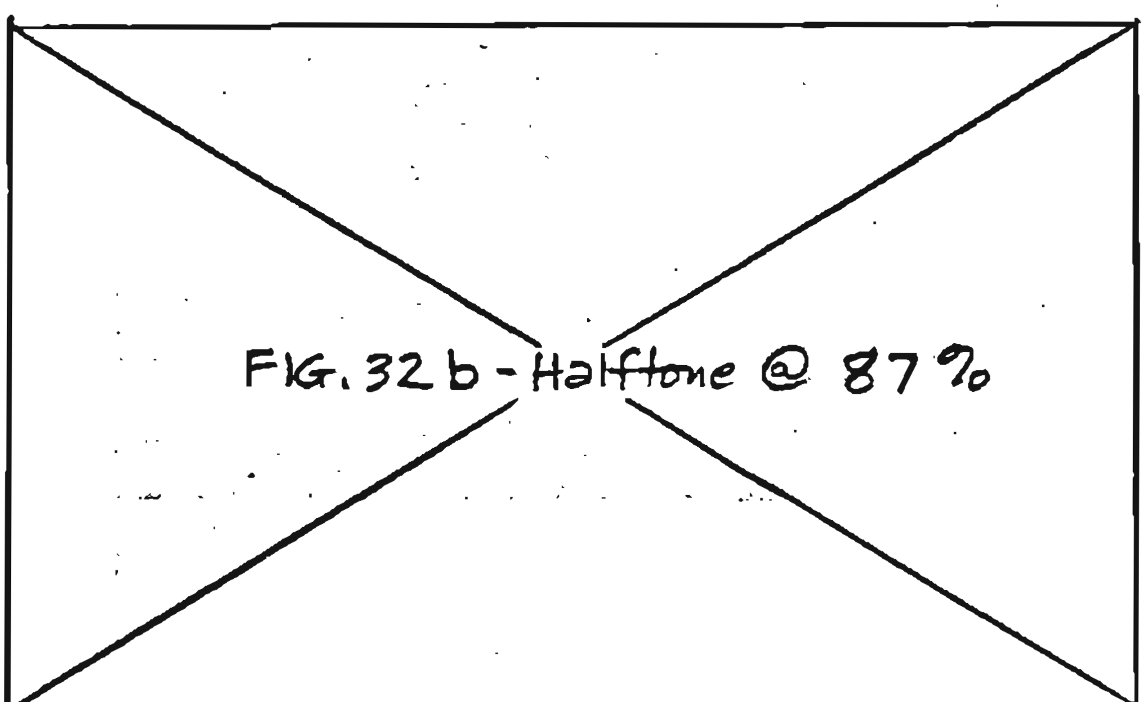
FIG. 31 - Halftone @ 100%

Figure 31.-- Recommended data-collection site at Canning River near Shublik Island; view downstream, August 13, 1975.

FIG. 31 - Halftone @ 100%



32a.-- View upstream.



32b.-- View downstream.

Figure 32.-- Recommended data-collection site at Hulahula River at traditional fishing site, August 13, 1975.

Fig. 32 a - Halftone @ 100%

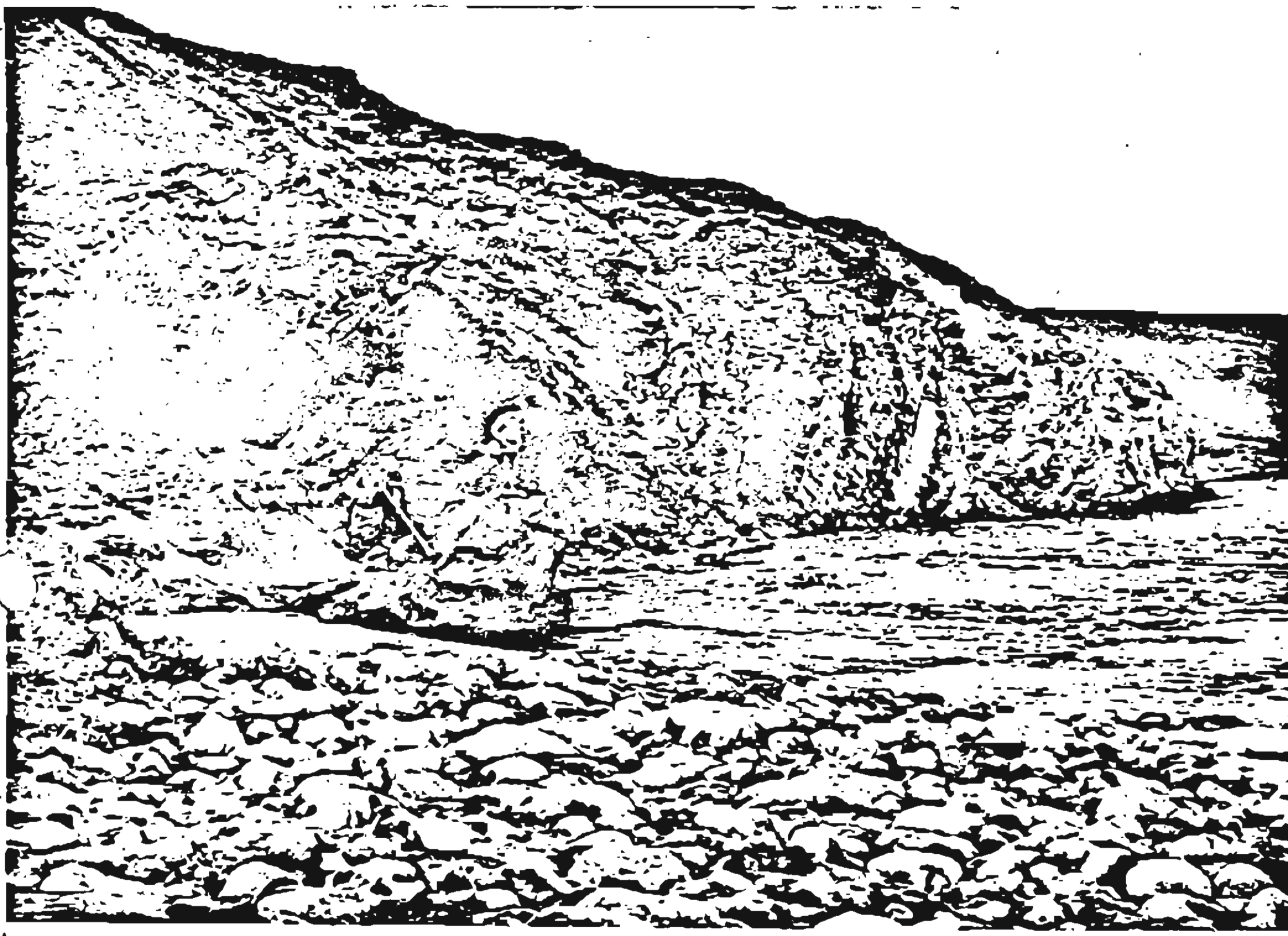


Fig. 32 b. - Halftone @ 87%

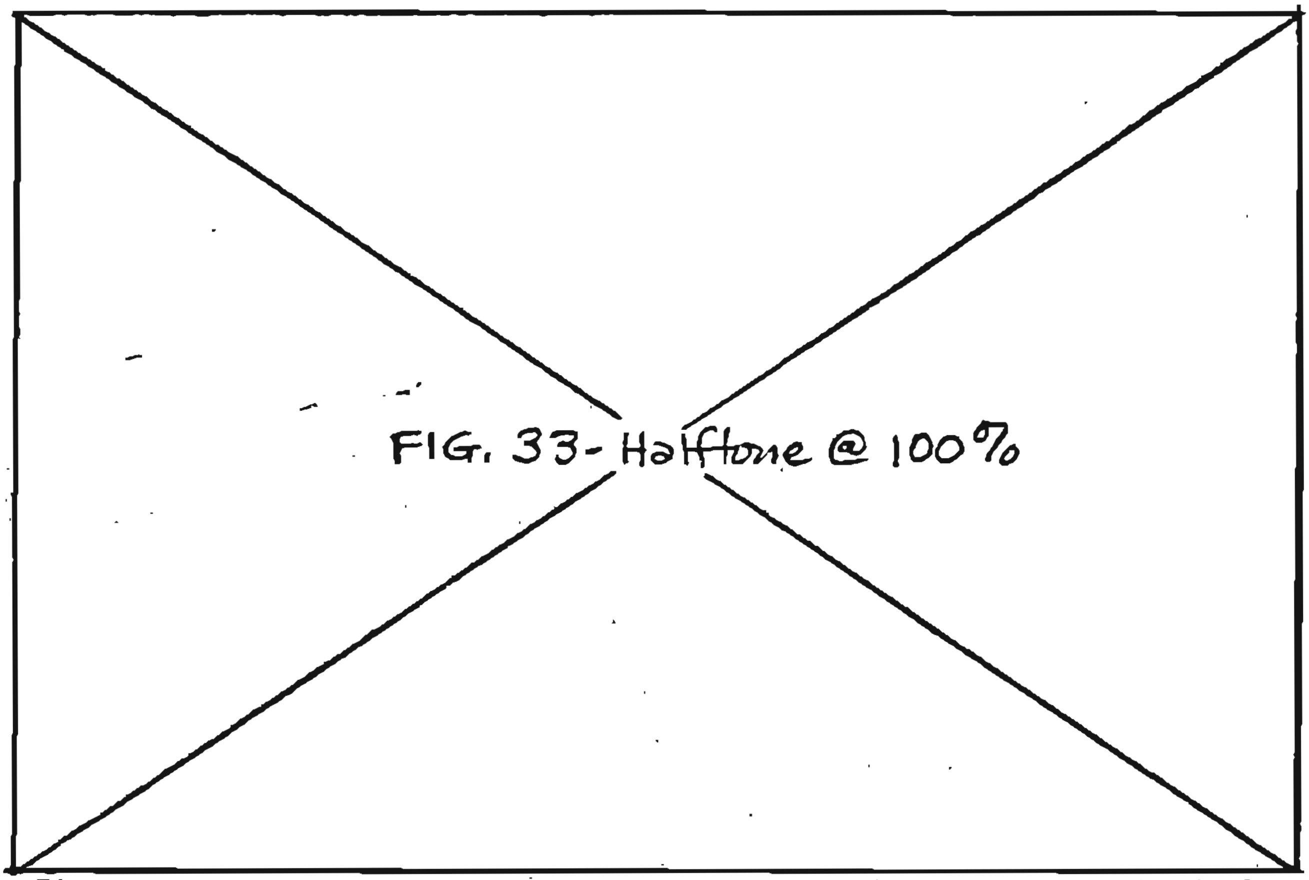


Figure 33.-- Recommended data-collection site on Colville River at head of delta near Nuiqsut, August 14, 1975.

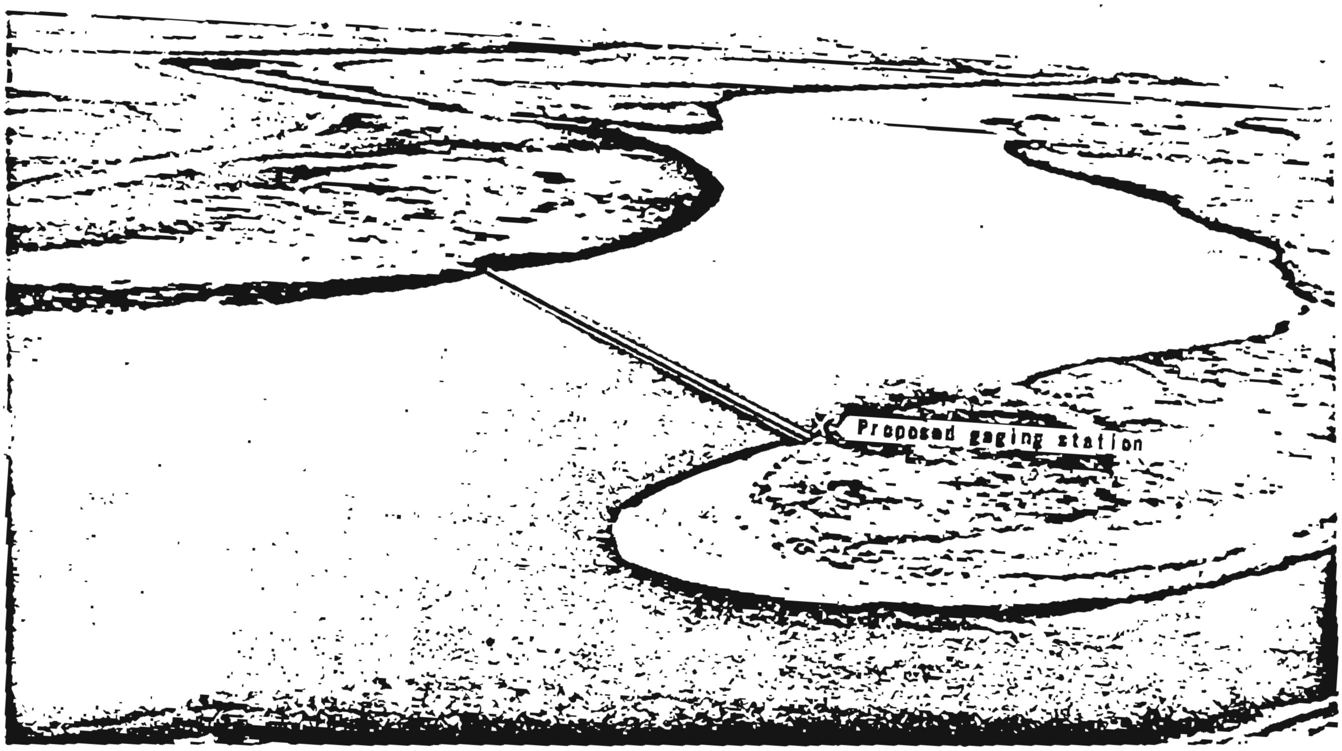


FIG. 33 - Halftone @ 100%

banks are steep and high. This reach has a nearly flat slope and may be subject to wind tide during low flow in the summer. Water was found at this site in April, but no flow velocity could be detected. It is doubtful whether there is streamflow at this site in late winter. Conditions for streamflow measurements are acceptable for the open-water season.

The Hulahula and Colville Rivers are recommended as streams for long-term data collection. These data would facilitate calculation of the regional flood frequency, and analyses of quantity and quality of streamflow would be useful for present and future planning.

Springs

Springs are the primary source of streamflow during most of the winter on the North Slope. Discharge from the springs appears to be relatively stable, but their variability in flow is unknown at present. Acceptable sites for continuous data collection exist at Sadlerochit Spring (fig. 34), at Flood Creek springs, and at the Saviukviayak springs. These sites have similar characteristics. The channels are fairly uniform and straight, and the streambeds are composed of medium-size cobbles. Except for Flood Creek springs, there is no evidence of significant icing formation at the springs.

A data-collection site on the Saviukviayak springs (fig. 35) would best define local drainage because it has a small drainage area [about 32 mi^2 (83 km^2)] in the high foothill area. Therefore, important data on runoff characteristics as well as spring discharge could be obtained at one site.

FIG 34-Halftone @ 100%

Figure 34.-- Sadlerochit Spring at east end of Sadlerochit Mountains, April 27, 1975.

FIG. 34 - Halftone @ 100%

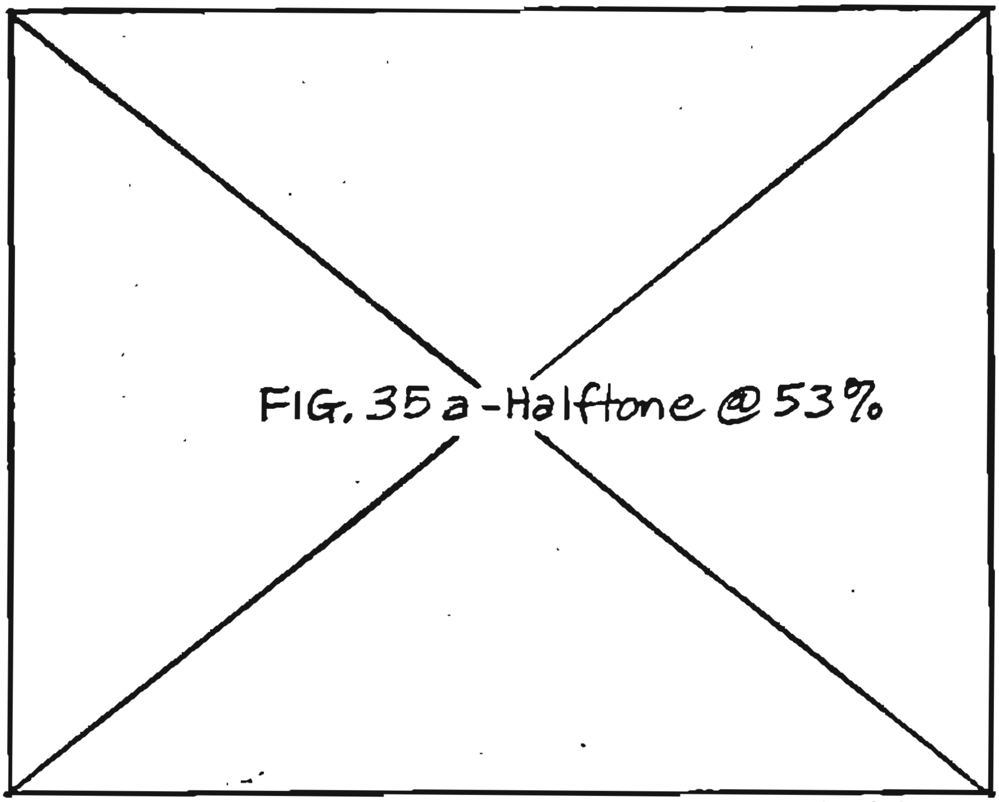


Figure 35a.-- Recommended data-collection site at Saviukviayak tributary spring, April 20, 1975.

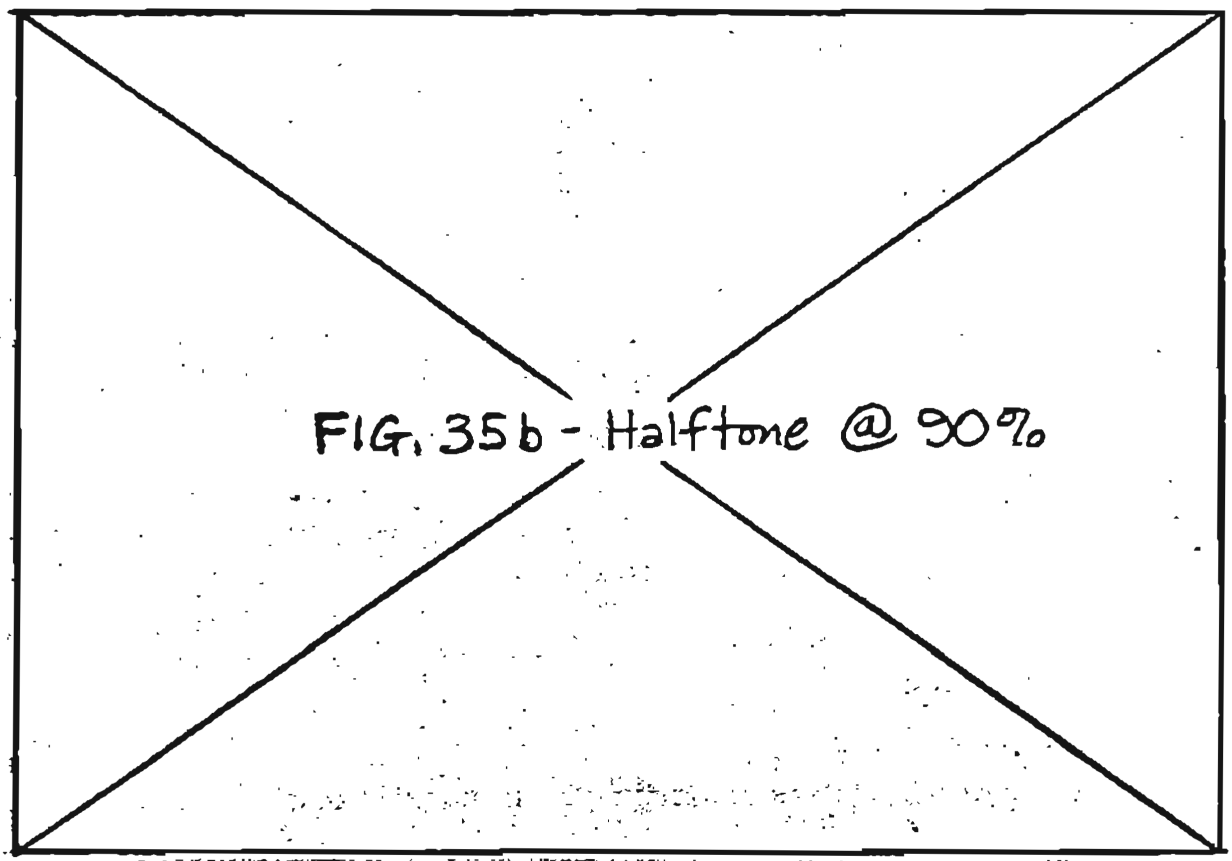


Figure 35b.-- Aerial view of recommended stream-gaging site.

(445) FIG. 35 - Reduce to 53% halftone

$4\frac{5}{16} \times 6\frac{1}{8}$

FIG. 35b - Halftone @ 90%

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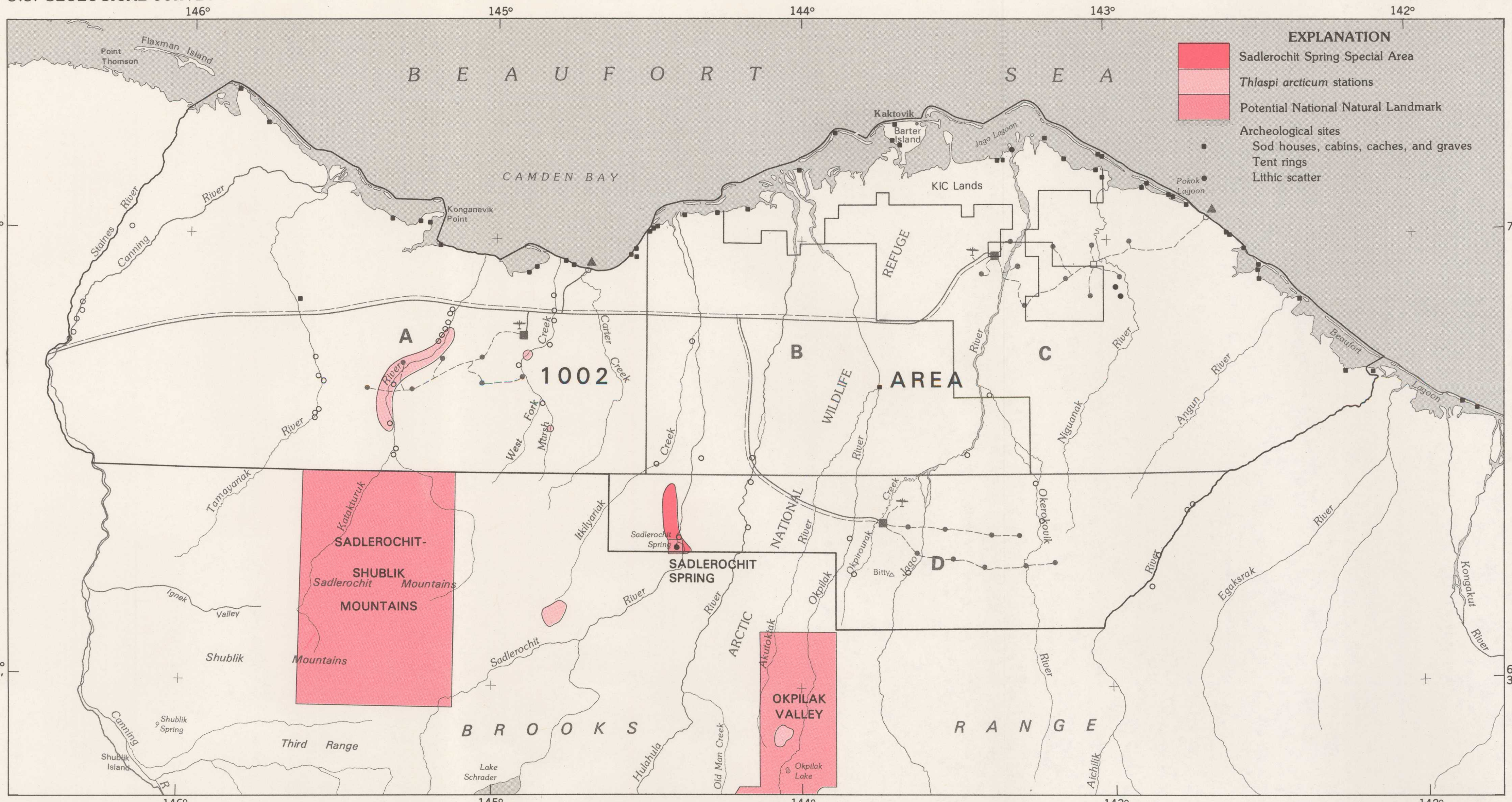
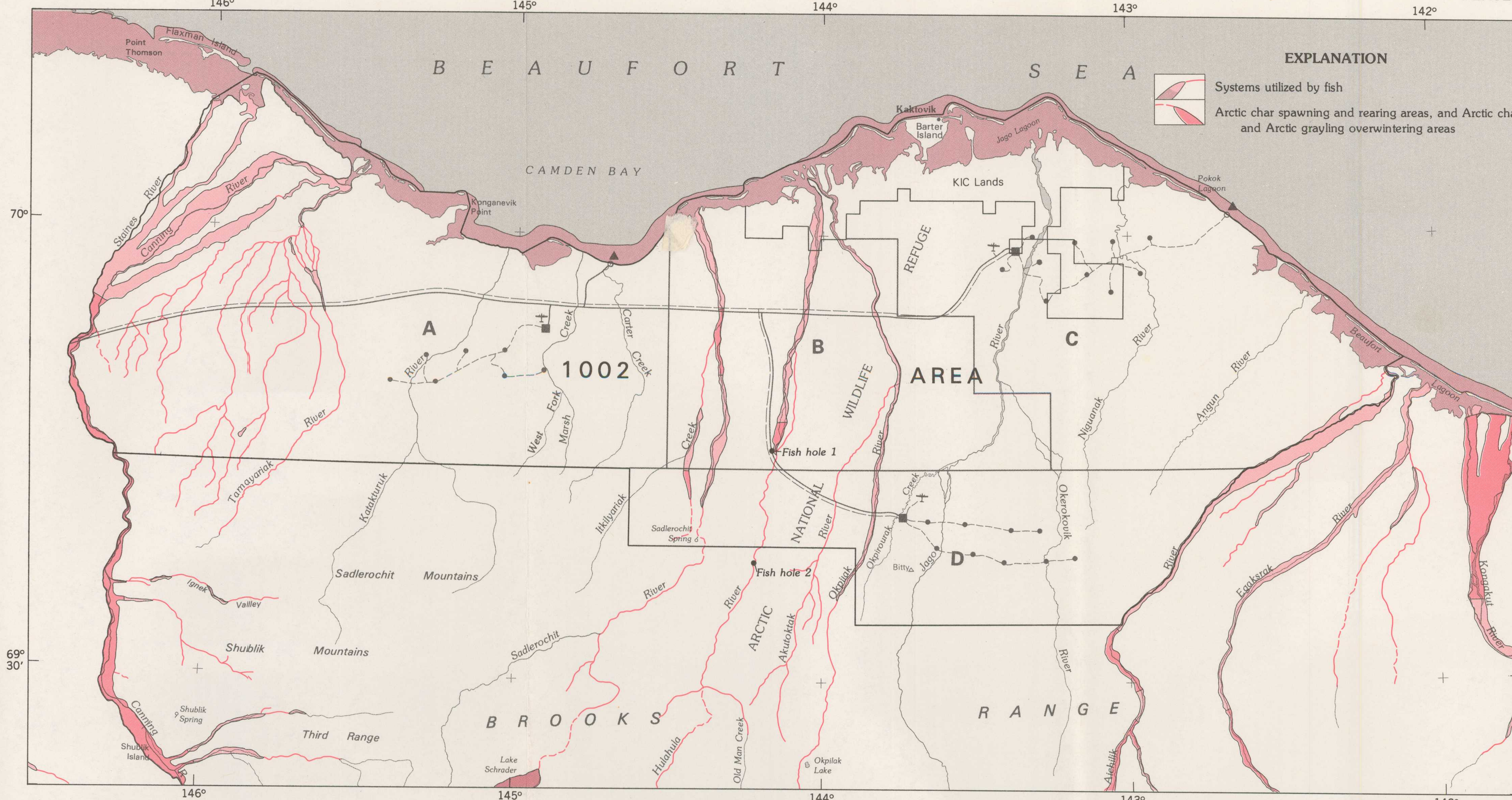
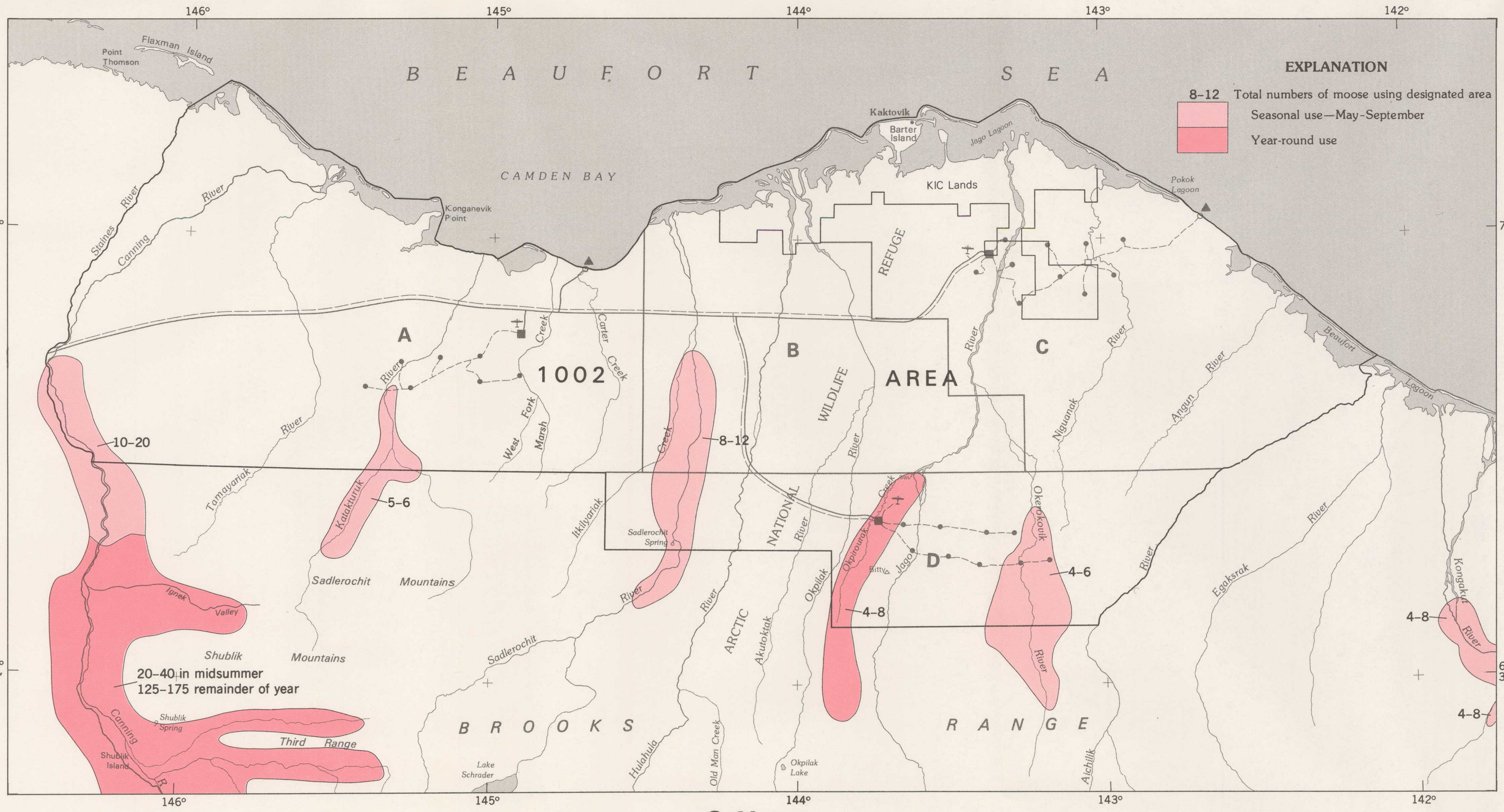
PREPARED IN COOPERATION WITH
THE U.S. FISH AND WILDLIFE SERVICE AND
THE U.S. BUREAU OF LAND MANAGEMENT



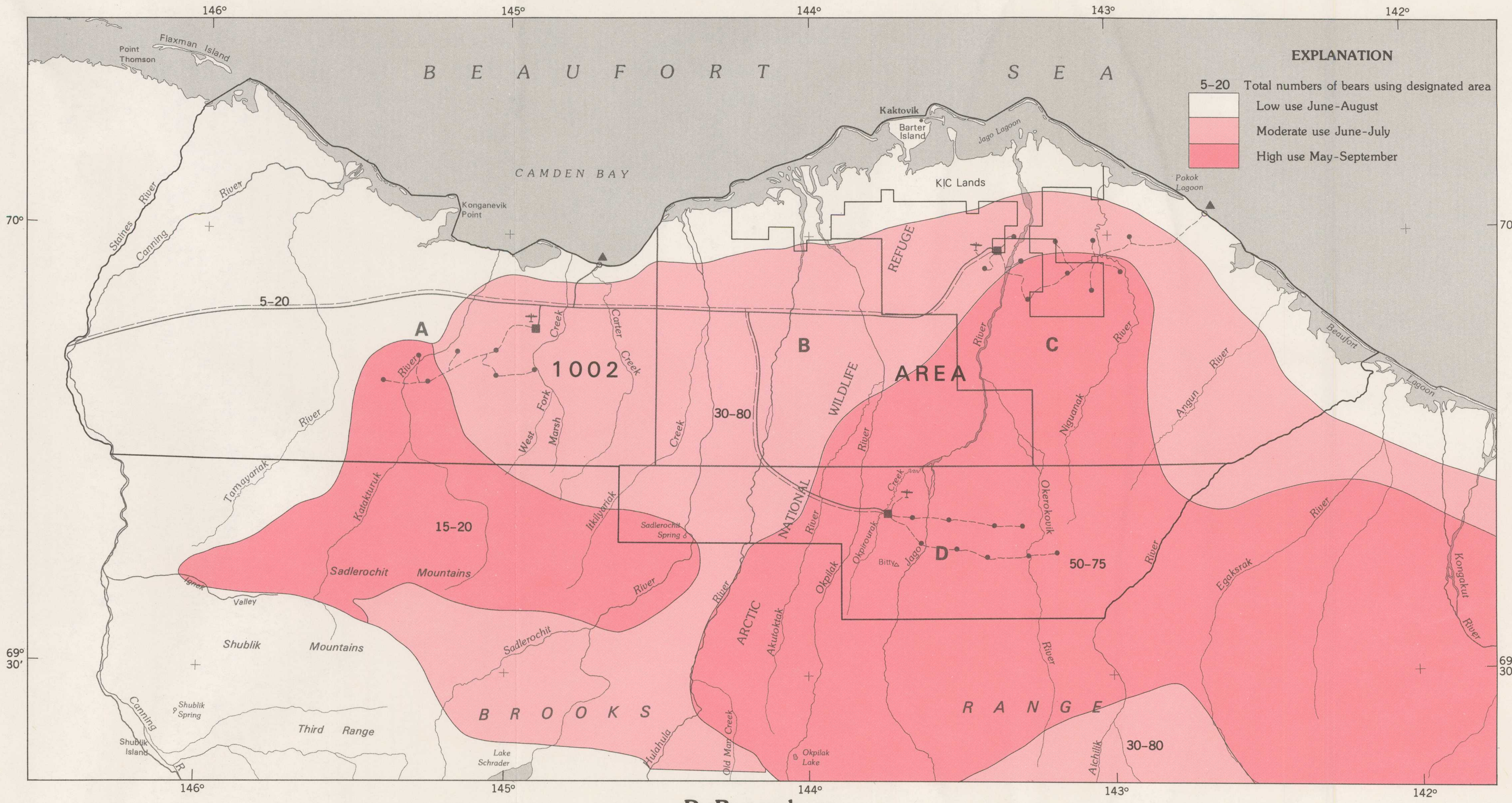
A. Potential national natural landmarks and archeological and other special sites



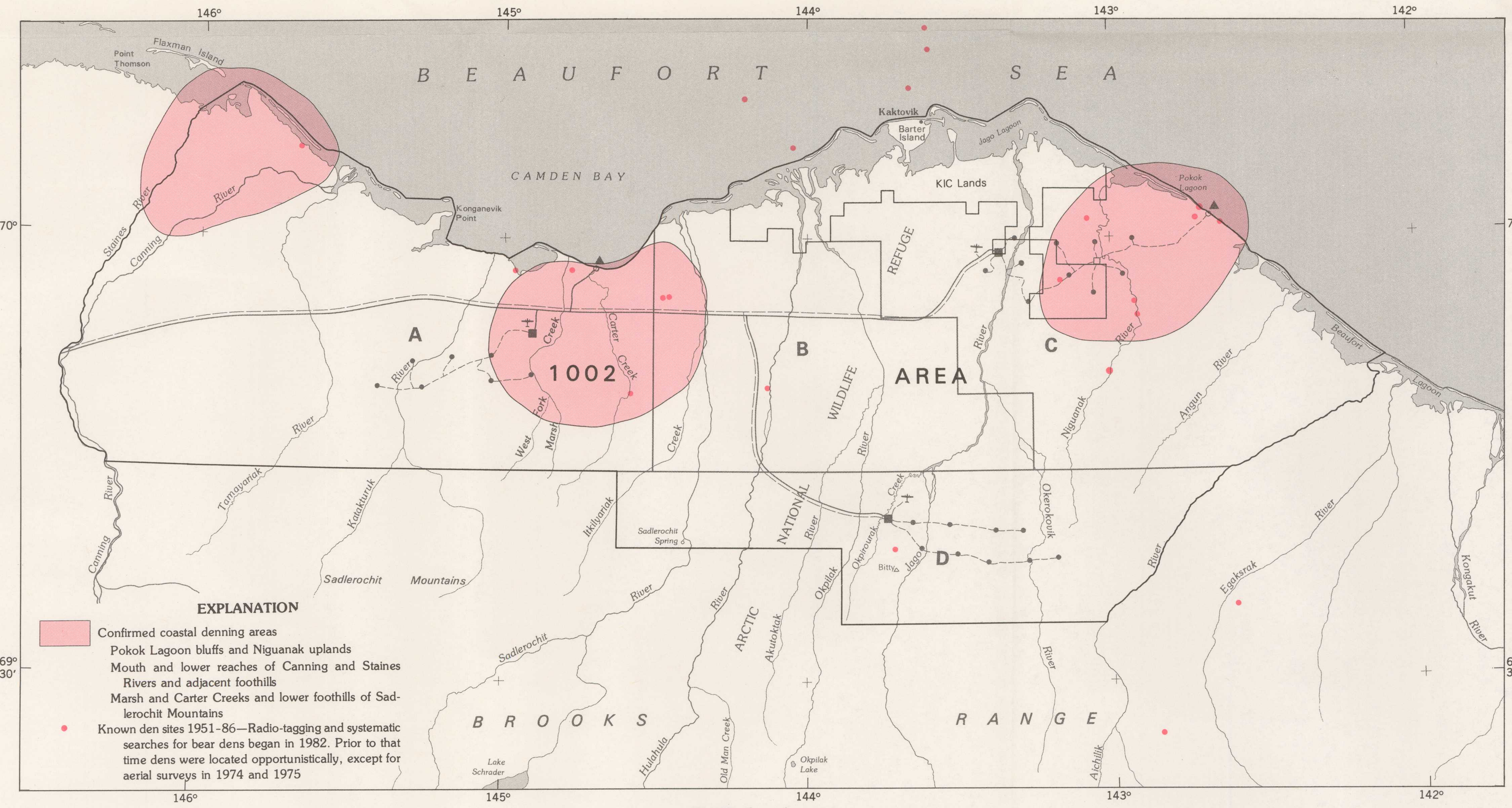
B. Fishery resources



C. Moose



D. Brown bear



E. Polar bear

Base from U.S. Geological Survey, scale 1:250,000;
Barter Island, Demarcation Point, and
Flaxman Island, 1955. Limited revision 1983
Mt Michelson, 1956. Limited revision 1983

EXPLANATION OF FULL-LEASING DATA
[Data from figure V-1, this report]

Possible facilities	Possible facilities
Central production facility	Airstrip—30 or 130 acres
90 acres	Haul road
40 acres	Connecting road
Drill pad	Seawater-treatment plant
23 acres	Port facility
Pipeline	B Assessment block discussed in text

SCALE 1:500 000

10 0 10 20 30 40 50 MILES

10 0 10 20 30 40 50 KILOMETERS

MAPS OF ARCHEOLOGICAL AND NATURAL AREAS, FISHERY, MOOSE, BROWN BEAR, AND POLAR BEAR RESOURCES IN THE 1002 AREA, ARCTIC NATIONAL WILDLIFE REFUGE, ALASKA

Compiled by the U.S. Fish and Wildlife Service

WINTER WATER SOURCES
AND
WINTER HABITAT FOR FISH AND WILDLIFE
ARCTIC ALASKA
MARCH 1977

SCALE

10 0 10 20 30 40 MILES

10 0 10 20 30 40 50 KILOMETERS

Prepared by Arctic Environmental Information and Data Center

Legend

Water Use by Fish and Wildlife (overwintering)

- Known Sites (river)
- Possible Sites (river)
- Known Sites (lake)
- Possible Sites (lake)

Icings - source

- Sloan et al. 1976
- U.S. Geological Survey Files
- Landsat Interpretation

Boundaries

- Arctic Region - Study Area Boundary
- Coastal Lake Province Boundary (Carson and Hussey 1962)
- Boundary between Foothill and Mountain Physiographic Provinces

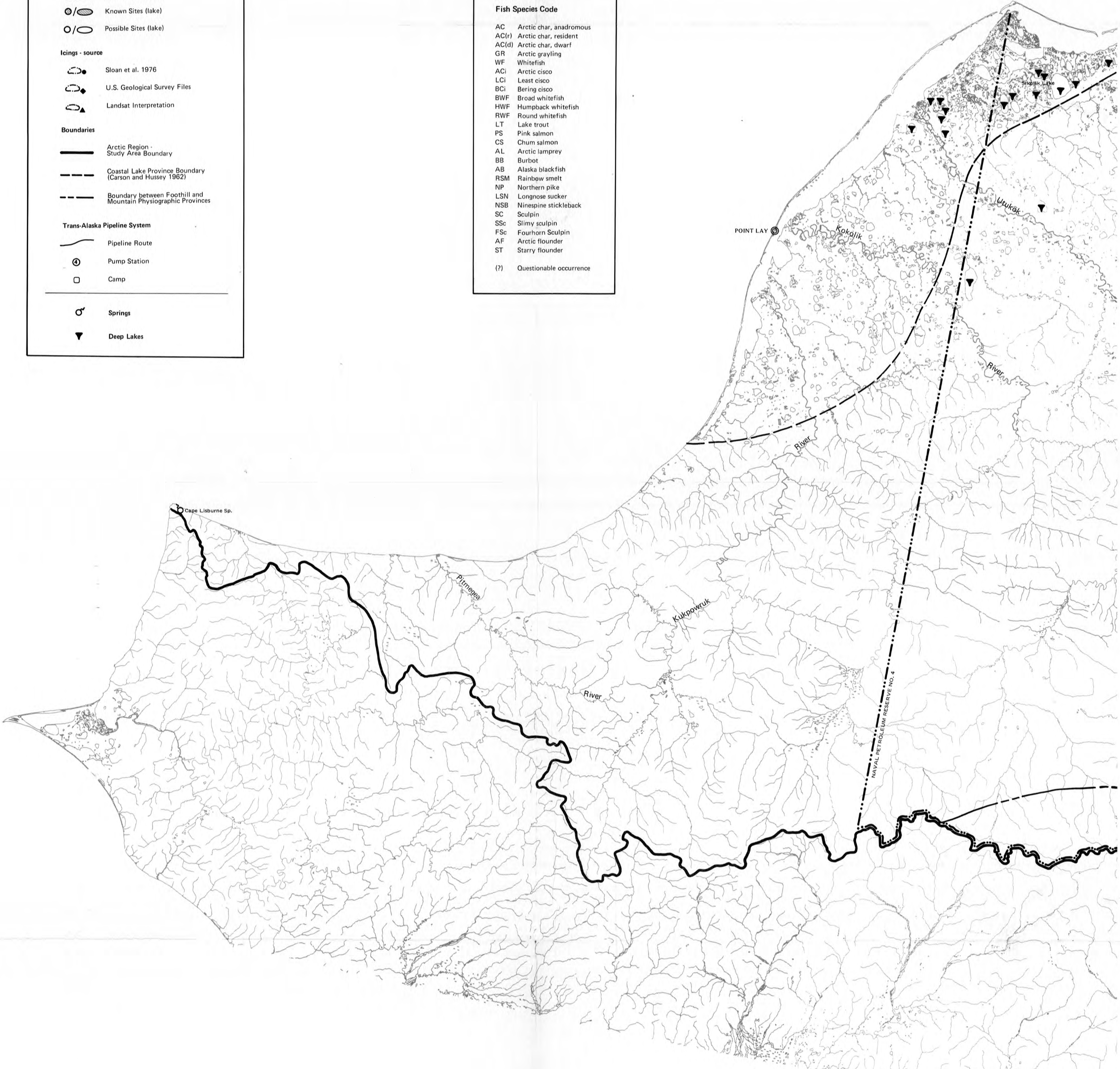
Trans-Alaska Pipeline System

- Pipeline Route
- Pump Station
- Camp

- Springs
- Deep Lakes

Fish Species Code

AC	Arctic char, anadromous
AC(r)	Arctic char, resident
AC(d)	Arctic char, dwarf
GR	Arctic grayling
WF	Whitefish
ACi	Arctic cisco
LCi	Least cisco
BCi	Bering cisco
BWF	Broad whitefish
HWF	Humpback whitefish
RWF	Round whitefish
LT	Lake trout
PS	Pink salmon
CS	Chum salmon
AL	Arctic lamprey
BB	Burbot
AB	Alaska blackfish
RSM	Rainbow smelt
NP	Northern pike
LSN	Longnose sucker
NSB	Ninespine stickleback
SC	Sculpin
SSc	Slimy sculpin
FSc	Fourhorn Sculpin
AF	Arctic flounder
ST	Starry flounder
(?)	Questionable occurrence



Winter utilization of freshwater habitats by fish is limited to unfrozen pools, channels, or pockets in rivers or in unfrozen lakes. Much of the coastal nearshore region to a depth of about two meters, and many of the coastal and tundra lakes, freeze to the bottom, and therefore are unavailable to fish. Consequently, fish populations, often of several year-classes as well as developing eggs, are restricted to open waters in rivers and streams, the deeper lakes, and that part of the marine environment which is greater than two meters in depth. Due to this restriction, winter is a critical period for all life cycle phases of freshwater fish.

Overwintering areas identified on this map may change in areal extent annually. As streams rechannel and groundwater flow pattern changes with season, the amount of available habitat in a given identified overwintering area may subsequently change.

Late fall surveys may indicate populations of fish spawning in a particular area, but as winter ensues these adults may move away from this area into other up- or downstream areas to take advantage of protective ice cover. This normal behavioral activity naturally enlarges the size of the overwintering areas.

Imikpuk Lake
BARROW
Emaiksoun Lake
Ikroavik Lake
LCi
BWF
NSB
Kimouksik Lake
Lake Sungovoak
Reindeer Lake
Sukok Lake
Lake Tusikvoak
Evrulivik Lake
Kilusiktok Lake
Ekalgruak Lake
Sisgravik Lake
River
Historical records indicate burbot may overwinter in the Meade and Inaru Rivers
River
WAINWRIGHT
Eskimo Fishing Area for RSM (Sloan 1976)
Inaru
Lake Itinik
Kuk
Meade
River
Ikmakrak Lake
ATKASOOK
Alaska blackfish and ninespine stickleback occur in many coastal and tundra lakes
LCi
LT
Many large lakes in this region support resident lake trout populations
Ikpikpuk
Eskimo Fishing Camp (Sloan 1976)
Historical records indicate rainbow smelt may overwinter in the Kuk River
River
Patigtitak Lake
Nuwuk Pond
Sakmalik Lake
NSB
Citellus Lake
Ahyagat Lake
LCi
LT
River
River
Meade
River
Ikpikpuk
Titaluk
River
Colville
River
Noluck Lake
GR
Liberator Lake
GR
West Smith Mountain Lake
Tukuto Lake
Lake Betty
Northern pike may inhabit lakes adjacent to the Killik River.
Kurupa Lake
Cascade Lake
AC(r)
GR
LT
RWF
Killik
River

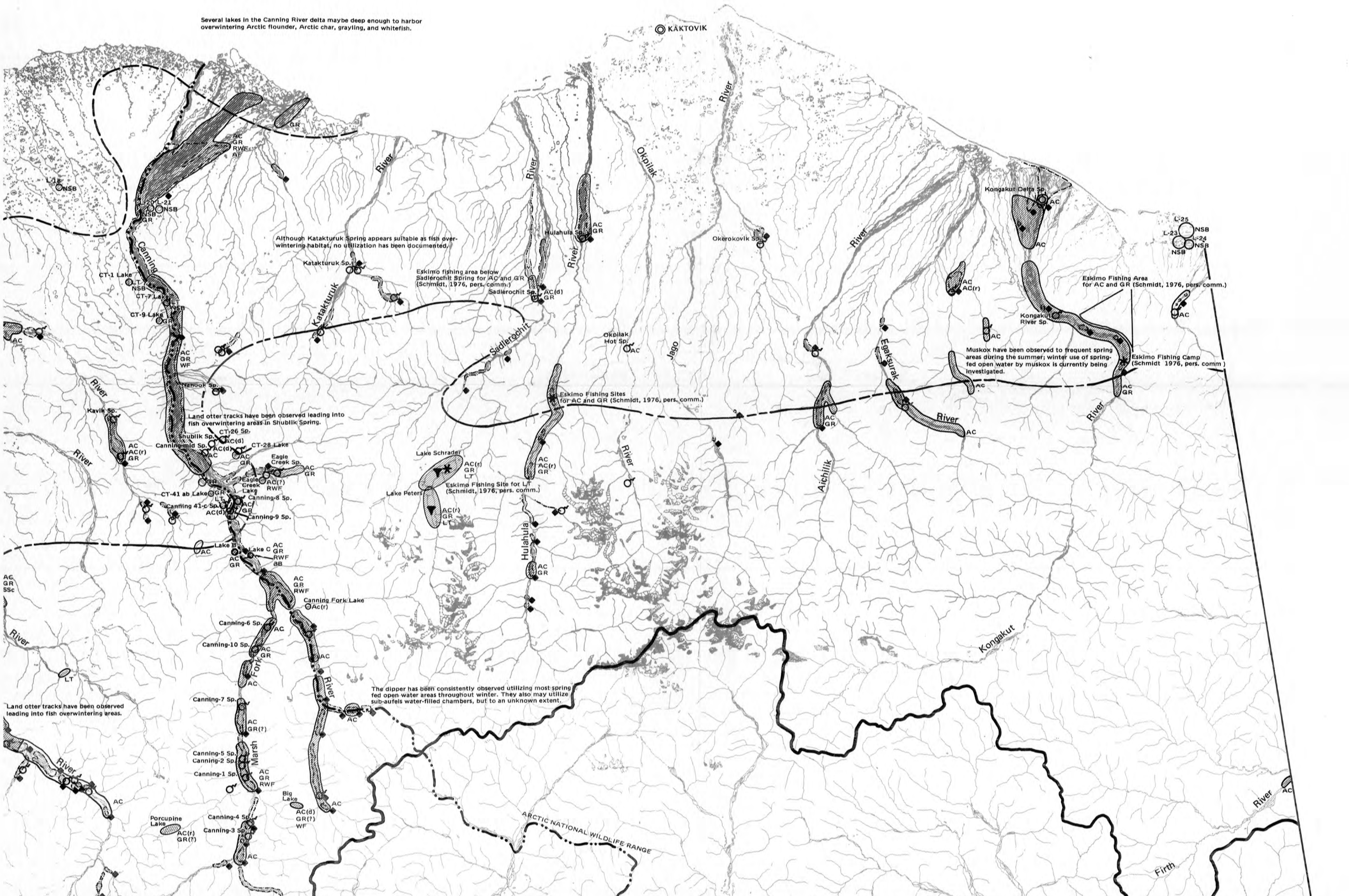
Nalagkruk Lake
Okalik Lake
Teshekpuk Lake
GR
LT
ACi
LCi
DWF
Sandune Lake
Square Lake
NUIQSUT
Nanuk Lake
Potential whitefish spawning grounds in the Colville River delta
Shirukak Lake
Arctic lamprey may inhabit the Colville River
Colville
River
Itkillik
Anaktuvuk
Kuparuk
NAVAL PETROLEUM RESERVE NO. 4
Wildcat Location (possible 1976-1977)
Sagavanirktok
Sagavanirktok Lake
A consistently used overwintering area near Sagwon Bluffs has become more shallow in recent years.
Echooka
Echooka Sp.
Ivishak
Ivishak Sp.
Kavik
Shaviovik
Mature non-spawning char may be spatially separate from spawning char in the Kavik River, possibly overwintering in the Kavik/Shaviovik drainage.
Land otter tracks have been observed leading into fish overwintering areas.
Lupine
Lupine Sp.
Ribdon
Ribdon Sp.
Elusive Lake
Raptorial birds utilize overwintering fish from open water springs on the Ribdon River
Anaiiorak Lake
Land otter tracks have been observed leading into open water areas.
Chandler
Toolik Lake
Campsite Lake
Island Lake
Upper Kuparuk Lakes
Southwest arm of Galbraith Lake may have open water in winter
Galbraith Lake
Aufeis Lake
Tee Lake
Sagavanirktok Sp
NOTE: One orifice is reported to originate from a pingo
Itkillik Lake
Shainin Lake
Tulugak Lake
White Lake
Little Chandler Lake
Chandler Lake
Eleanor Lake
ANAKTUVUK PASS

Marine overwintering areas are generally outside the zone of bottomfast ice. Areas are generally greater than six feet in depth, and although temperatures range down to -4°C, the water does not freeze due to high salinity. Fish are adapted to withstand these temperatures without freezing of body fluids. Marine fish overwintering here include fourhorn sculpin, Arctic cod, Arctic flounder, and others.

River delta overwintering areas extend inland from the area of bottomfast ice to the maximum extent of saltwater intrusion. This area is characterized by depths greater than six feet which do not freeze to the bottom due to high salinity. Fish which overwinter in this area include Arctic cisco, least cisco, fourhorn sculpin, burbot, and humpback whitefish. Arctic char, an anadromous fish, and many freshwater species such as grayling, slimy sculpin, round whitefish, and longnose sucker will not occur seaward of the maximum extent of saltwater intrusion. These fish are relatively intolerant of salinity and cannot withstand subfreezing temperatures.

In areas **upstream,** away from saline influences, are found overwintering areas near springs and in deeper pockets of rivers and streams. These areas do not freeze to the bottom in winter and provide the only aquatic habitat available in the river systems. They are also important as areas in which eggs and fry can survive. Fish found here include freshwater species and the anadromous Arctic char. Feeding is very limited during winter months.

Coastal lakes are near or connected to the Beaufort Sea. Several contain populations of grayling, Arctic char, and broad whitefish. Deeper lakes support winter fish populations, but some serve only as summer feeding areas. Most shallow **tundra lakes** and ponds freeze to the bottom during the winter and do not support permanent fish populations. A few, however, which are deep enough or which are connected by an unfrozen outlet to drainages which can support overwintering fish may have populations of ninespine stickleback or grayling. **Deeper lakes** located at the headwaters of major river drainages may support permanent populations of Arctic char, lake trout, and grayling.



NOTE: This map is a generalized portrayal of data. This same information is also available on 1:250,000 scale draft overlays to U.S. Geological Survey topographic maps. The overlays are archived at AEIDC, 707 "A" Street, Anchorage, Alaska 99501.

Alaska Fisheries Technical Report Number 27

SUMMER DISTRIBUTION OF ARCTIC FISHES IN THE 1002 AREA OF THE ARCTIC NATIONAL WILDLIFE REFUGE, ALASKA, 1991, WITH SPECIAL EMPHASIS ON SELECTED LAKES, TUNDRA STREAMS, AND THE SADLEROCHIT RIVER DRAINAGE

December 1994

Region 7
U.S. Fish and Wildlife Service • Department of the Interior

Alaska Fisheries Technical Report Number 27

Summary Distribution of Arctic Fishes in the 1002 Area of the Arctic National Wildlife Refuge, Alaska, 1991 with emphasis on selected lakes, tundra streams, and the Sadlerochit River drainage

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Alaska Fisheries Technical Report Number 27

Summer Distribution of Arctic Fishes in the 1002 Area of the Arctic National Wildlife Refuge, Alaska, 1991 with emphasis on selected lakes, tundra streams, and the Sadlerochit River drainage

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Abstract.—The summer distribution of Arctic fishes on the coastal plain of the Arctic National Wildlife Refuge was investigated in 19 lakes, 20 tundra streams, and the Sadlerochit River drainage during 1991. Fish sampling occurred July 2 - September 24. All lakes were sampled once except one river-connected lake that was sampled July, August, and September. Tundra streams and the Sadlerochit River drainage were sampled in July and sites were resampled in August and September. Fyke nets were used to capture fish in the lakes and hook and line and electrofisher were used in the rivers and streams.

In 14 isolated lakes, ninespine stickleback *Pungitius pungitius* was the only species captured and in three lakes no fish were captured. The number of species was higher in river-connected lakes; where, in two lakes in the Canning River delta, Dolly Varden char *Salvelinus malma*, Arctic grayling *Thymallus arcticus*, Arctic cisco *Coregonus autumnalis*, least cisco *C. sardinella*, fourhorn sculpin *Myoxocephalus quadricornis*, and ninespine stickleback were captured. Ninespine stickleback ranged from 22 to 82 mm fork length (FL), Dolly Varden char were 170 - 237 mm FL, and Arctic cisco were 58 - 109 mm FL.

In the tundra streams, juvenile Dolly Varden char, ninespine stickleback, fourhorn sculpin, and juvenile and young of the year Arctic grayling were captured. Dolly Varden char were captured in twelve tundra streams but only in Nataroarok, Marsh, and Carter creeks were juveniles captured during both July and August. Ninespine stickleback were captured in 18 streams but not during all sampling periods. Arctic grayling were found in two streams and fourhorn sculpin in one stream. Dolly Varden char ranged from 63 - 237 mm FL and ninespine stickleback were 20 - 89 mm FL.

In the Sadlerochit River drainage, resident Dolly Varden char, three life history stages (young of the year, juvenile, and adult) of Arctic grayling, and ninespine stickleback were captured. Dolly Varden char were captured during all three sampling periods and were distributed throughout the drainage although they were not captured at all sites. Juvenile and adult Arctic grayling were captured in July and August. Young of the year Arctic grayling were captured in August and September. Adult and juvenile Arctic grayling were captured in the Kekiktuk River in September. Dolly Varden char in the drainage ranged from 68 to 233 mm FL. Adult Arctic grayling were 304 - 369 mm FL, juveniles were 86 - 242 mm FL, and young of the year were 11 - 32 mm FL.

Introduction

The 1002 area, on the coastal plain of the Arctic National Wildlife Refuge (Arctic Refuge), was designated by the U.S. Congress for possible oil and gas exploration and development under the Alaska National Interest Lands Conservation Act of 1980 (U.S. Public Law 96-487). Should such activities be allowed, fishery resources could be affected by the construction and placement of roads and pipelines, gravel removal, oil spills, and water diversions.

Freshwater fishery investigations in the 1002 area prior to 1989 (Ward and Craig 1974; Smith and Glesne 1983; Daum et al. 1984; West and Wiswar 1985; Wiswar et al. 1987; West and Frugé 1989; Corning, unpublished report-a) are limited in area sampled, and frequency and duration of sampling. In 1989, multiple sites in four rivers were sampled several times during the open water season (Wiswar 1991; Corning, unpublished report-b). Also in 1989, 52 lakes on the coastal plain were sampled (Elliott 1990; Trawicki et al. 1991). The results of the 1989 investigations indicated that fish were more widely distributed in rivers and lakes than previously documented. In order to assess impacts from potential oil and gas activities, and recommend mitigation measures for such activities, surveys begun in 1989 were continued in the summers of 1990 (Wiswar 1992) and 1991. This report is divided into three sections: lakes, tundra streams, and the Sadlerochit River drainage. Objectives and methods are defined under each section.

Study Area

The rivers and lakes are located on the Arctic coastal plain and within the boundary of the Arctic Refuge (Figures 1 and 2). The coastal plain is underlain by continuous permafrost. The climate is arctic marine and is characterized by long, cold winters and short, cool summers. Mean monthly temperatures are below 0°C nine months of the year (NOAA 1987). February is the coldest month with a mean monthly temperature of minus 28.9°C. July is the warmest month with an average temperature of 4.4°C. Snowmelt begins in the foothills in late May and is usually rapid (10-14 days). Rivers run full during this period with flows subsiding in late June or early July. Precipitation and storm events may increase flows again in July and August. Lakes become ice free by early July. Freeze-up on the coastal plain usually occurs in mid- to late September (Clough et al. 1987).

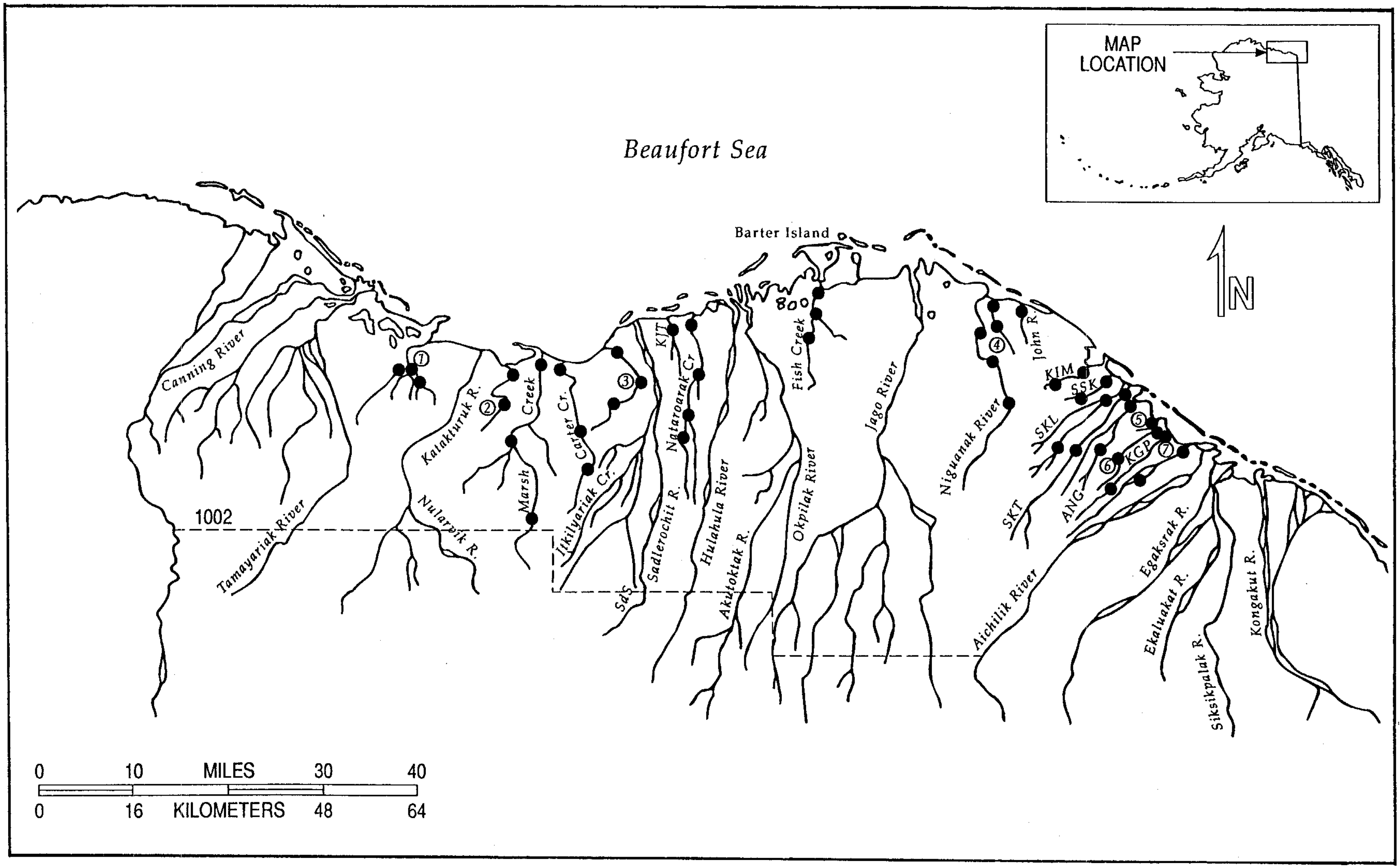


FIGURE 1.—Rivers and streams in the 1002 area of the Arctic National Wildlife Refuge, Alaska. SdS = Sadlerochit Spring, KJT = Kajutakrok Creek, KIM = Kimikpaurauk River, SSK = Siksik River, SKL = Sikrelurak River, SKT = Sikutaktuvik River, ANG = Angun River, KGP = Kogotpak River, streams 1-7 are unnamed, ● = sites in tundra streams sampled July - September 1991.

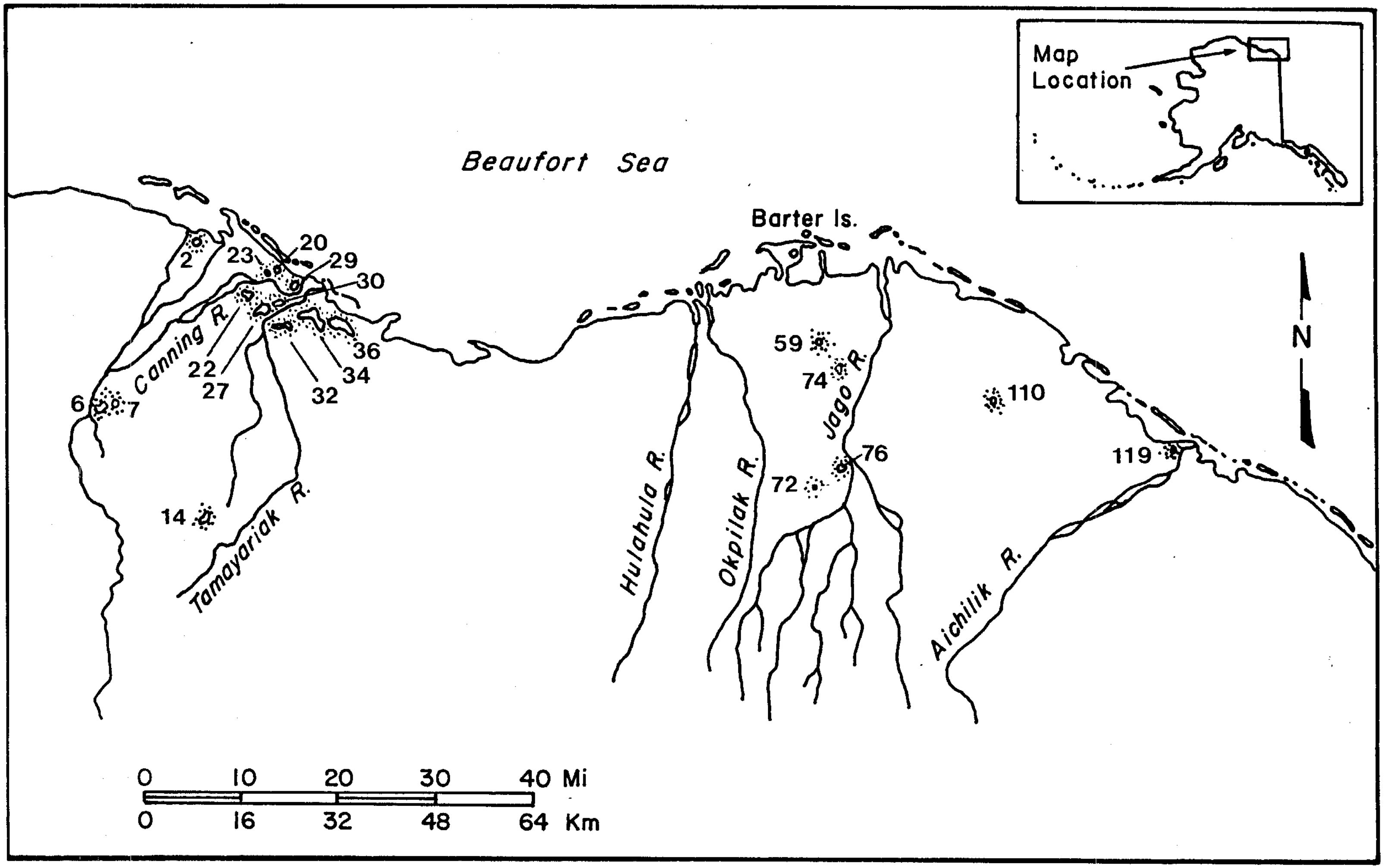


FIGURE 2.—Lakes in the 1002 area of the Arctic National Wildlife Refuge, Alaska sampled during the summer 1991.

Lakes on the Arctic coastal plain in the 1002 area

Fourteen lakes were sampled during the summer of 1973 (Ward and Craig 1974; Table 1). All but two lakes were in the Canning River delta. Arctic grayling *Thymallus arcticus*, Dolly Varden char *Salvelinus malma*, broad whitefish *Coregonus nasus*, round whitefish *Prosopium cylindraceum*, Arctic flounder *Liopsetta glacialis*, and ninespine stickleback *Pungitius pungitius* were captured in four river-connected lakes but not all species were caught in each lake. Arctic grayling and ninespine stickleback were captured in one isolated lake. In 1986, nine isolated lakes on the coastal plain were sampled and ninespine stickleback were captured in three lakes (West and Frugé 1989; Table 1).

Between 1989 and 1990, depth measurements along transects in 119 lakes in the 1002 area were used to quantify water availability (Elliott 1990; Trawicki et al. 1991). Ninespine stickleback were captured or observed in 36 of the 54 lakes surveyed for fish. Maximum depth in lakes where fish were found ranged from 0.7 to 7.6 m.

The objectives of this study in 1991 are to:

1. Determine spatial distribution of arctic fishes in river-connected and isolated lakes within the 1002 area.
2. Determine length frequency and weights for arctic fishes.

Methods

Nineteen lakes on the coastal plain were sampled for fish distribution during the summer 1991 (Figure 2). Lakes greater than 2.7 m maximum depth were initially selected for sampling (Elliott 1990; Trawicki et al. 1991). The depth criteria was based on late winter ice thickness and under ice water depth. In arctic lakes, ice normally does not exceed 2 m (Wilson et al. 1977), and fish have been captured under ice in water as shallow as 0.7 m deep (Craig 1989). Seventeen of the 19 lakes are deeper than 2.7 m (Elliott 1990; Trawicki et al. 1991). Thirteen lakes were sampled on July 5-13, six lakes on August 16-19, and two lakes on September 22, 1991. Lake 27, a river-connected lake in the Canning River delta, was sampled during all three periods. The numbering system used for the lakes follows that of Trawicki et al. (1991).

Fish were collected with fyke nets (0.6 cm mesh, 0.8 m D-frame opening, 3 m long wings and 9.1. m long lead).

Fish captured were counted and measured to the nearest mm fork length (FL) or total length for fish species with truncate or rounded caudal fins. Fish over 200 g were weighed to the nearest 10 g and fish less than 200 g to the nearest 0.1 g. Smaller fish (<200 mm FL) were placed in a solution of tricaine (MS 222) before measuring. When a large (>100) number of fish was captured a random subsample was measured.

Results

Fish distribution.—Two lakes sampled are river connected. Lakes 27 and 30 (Table 2; Figure 2), are connected by a short channel (about 25 m long), and lake 30 is connected to a channel of the Canning River. Juvenile Dolly Varden char (N = 4) and three life stages of Arctic grayling (N = 2 adult, 11 juveniles, and 2 young of the year) were captured in one or both lakes within the three sampling periods. Juvenile Arctic cisco *Coregonus autumnalis* (N = 12), least cisco *C. sardinella* (N = 1), fourhorn sculpin *Myoxocephalus quadricornis* (N = 6), and ninespine stickleback (N = 7) were also captured.

Ninespine stickleback was the only species captured (N = 1 to 2,730) in 14 isolated lakes. No fish were captured in lakes 29, 59, and 72.

Biological characteristics.—Juvenile Dolly Varden char captured in lakes 27 and 30 ranged from 170 to 237 mm FL (Table 3). Juvenile Arctic cisco in July ranged from 58 - 109 mm FL. Ninespine stickleback from 16 lakes ranged from 22 to 82 mm FL. Adult size Arctic grayling captured in August were 294 - 297 mm FL; juveniles in July and August were 91 - 240 mm FL, and young of the year in September were 42 - 48 mm FL.

Discussion

The number of different fish species captured was greater in river-connected lakes than in isolated lakes in the 1002 area. Juvenile Dolly Varden char, juvenile Arctic cisco, Arctic grayling, fourhorn sculpin, least cisco, and ninespine stickleback were captured in river-connected lakes within the Canning River delta. Ward and Craig (1974) also captured round whitefish, broad whitefish, and Arctic flounder in other river-connected lakes in this area.

Ninespine stickleback was the only species captured in 14 of the 17 isolated lakes sampled. The wide distribution and occurrence of ninespine stickleback in isolated lakes compares favorably with other studies on the coastal plain (Ward and Craig 1974; West and Frugé 1989; Elliott 1990; Trawicki et al. 1991). At higher elevations (> 300 m), isolated lakes located in the foothills support Dolly Varden char, lake trout *Salvelinus namaycush*, and Arctic grayling populations (Daum et al. 1984; Wiswar 1992).

Arctic cisco were captured in lake 27 on July 12. This species had not been captured in inland waters of the Arctic Refuge prior to 1991. Lake 27, which is 5.5 m deep (Trawicki et al. 1991), may have provided overwintering habitat for these Arctic cisco during the previous winter. Arctic cisco are anadromous and occur in the nearshore coastal waters along the Arctic Refuge during the open water season (West and Wiswar 1985; Wiswar and West 1987; Frugé et al. 1989; Palmer and Dugan 1990; Underwood et al. 1992). Overwintering areas in Alaska have only been documented to the west of the refuge in the Colville River (Moulton 1989) and Sagavanirktok River delta (Schmidt et al. 1989).

TABLE 1.—Species occurrence documented in lakes in this study prior to 1991.

Lake	Date previously sampled	Species present
2	Jul 1990[a]	No fish documented
6	Aug 1973, Aug 1989[a]	Arctic grayling, ninespine stickleback
7	Aug 1973[b], Aug 1989	Ninespine stickleback
14	Not sampled	
20	Jul 1990	No fish documented
22	Aug 1990[a]	No fish documented
23	Jul 1990	No fish documented
27	Jul 1989[a]	Ninespine stickleback
29	Jul 1973[b], Aug 1990	No fish documented
30	Jul 1973, Aug 1990	Dolly Varden char, round whitefish
32	Aug 1990	No fish documented
34	Jul 1973, Jul 1986[c], Aug 1989	Ninespine stickleback
36	Jul 1973, Jun 1989[a]	No fish documented
59	Aug 1990	No fish documented
72	Not sampled	
74	Jul 1989	Ninespine stickleback
76	Jul 1989	Ninespine stickleback
110	Jul 1986, Jun 1989	Ninespine stickleback
119	Aug 1989	Ninespine stickleback

[a] Elliott 1990; Trawicki et al. 1991
[b] Ward and Craig 1974
[c] West and Frugé 1989

TABLE 2.—Summary of capture information for fish caught by fyke nets in lakes in the 1002 area of the Arctic National Wildlife Refuge, July - September 1991. All lakes are deeper than 2.7 m except lakes 29 and 30. Lakes 27 and 30 are river-connected, all other lakes are isolated. ACi = Arctic cisco, DVC = Dolly Varden char, FHS = fourhorn sculpin, GR = Arctic grayling, LCi = least cisco, NSB = ninespine stickleback, a = adult, j = juvenile, yoy = young of the year.

Lake	Date sampled	Number of sites	Effort (h)	Species and life history stage	N
2	Aug 16	2	44.0	NSB	6
6	Jul 8	2	48.5	NSB	2,730
7	Jul 8	2	47.1	NSB	11
14	Jul 9	2	41.8	NSB	1
20	Aug 17	2	59.5	NSB	47
22	Jul 13	2	41.7	NSB	2
23	Aug 17	2	61.0	NSB	1
27	Jul 12	2	44.0	DVC j	2
				ACi j	12
				GR j	2
				NSB	5
27	Aug 16	2	48.5	DVC j	1
				GR a	2
				GR j	6
				LCi	1
27	Sep 22	1	43.0	GR yoy	1
				FHS	1
29	Jul 13	2	47.2		0
30	Sep 22	2	42.3	DVC j	1
				GR j	3
				GR yoy	1
				NSB	2
				FHS	5

TABLE 2.—Continued.

Lake	Date sampled	Number of sites	Effort (h)	Species and life history stage	N
32	Jul 12	2	42.7	NSB	3
34	Jul 10	4	98.2	NSB	10
36	Jul 11	4	98.2	NSB	38
59	Jul 6	2	44.0		0
72	Jul 5	2	48.0		0
74	Jul 6	2	44.5	NSB	2
76	Jul 5	2	49.8	NSB	6
110	Aug 19	2	51.5	NSB	17
119	Aug 19	2	47.3	NSB	7

TABLE 3.—Lengths and weights of fish captured in lakes in the 1002 area of the Arctic National Wildlife Refuge, July - September 1991. ACi = Arctic cisco, DVC = Dolly Varden char, FHS = fourhorn sculpin, GR = Arctic grayling, LCi = least cisco, NSB = ninespine stickleback, a = adult, j = juvenile, yoy = young of the year.

				Length (mm)			Weight (g)		
Lake	Date	Species	N	Mean	SD	Range	Mean	SD	Range
2	Aug 16	NSB	6	47.7	4.2	41-53			
6	Jul 8	NSB	195	36.4	4.2	26-51			
7	Jul 8	NSB	11	51.9	12.1	22-69			
14	Jul 9	NSB	1	32					
20	Aug 17	NSB	47	61.9	4.6	54-69			
22	Jul 13	NSB	2	46.0	2.0	44-48			
23	Aug 17	NSB	1	40					
27	Jul 12	DVC j	2	176.5	6.5	170-183	50.5	5.9	44.6-56.4
		ACi j	12	89.0	12.9	58-109	6.1	1.7	2.7-9.7
		GR j	2	177.0	33.0	144-210	58.6	28.9	29.9-87.7
		NSB	5	54.4	14.7	39-82			
	Aug 16	DVC j	1	206			77.8		
		GR a	2	295.5	1.5	294-297	265.0	15.0	250-280
		GR j	6	187.5	53.6	91-240	79.4	48.1	5.9-135.0
		LCi	1	307			320		
	Sep 22	GR yoy	1	42					
		FHS	1	187			52.6		
30	Sep 22	DVC j	1	237			117.8		
		GR j	3	141.7	36.6	94-183	33.5	22.8	7.2-62.8
		GR yoy	1	48					
		NSB	2	51	8.0	43-59			
		FHS	5	39.2	7.1	30-48			

TABLE 3.—Continued.

				Length (mm)			Weight (g)		
Lake	Date	Species	N	Mean	SD	Range	Mean	SD	Range
32	Jul 12	NSB	3	52.3	5.7	45-59			
34	Jul 10	NSB	10	48.4	7.9	38-63			
36	Jul 11	NSB	38	42.7	5.8	31-60			
74	Jul 6	NSB	2	52.5	4.5	48-57			
76	Jul 5	NSB	6	49.2	7.6	39-62			
110	Aug 19	NSB	17	44.6	10.5	30-68			
119	Aug 19	NSB	7	39.3	4.3	31-46			

Tundra streams on the Arctic coastal plain in the 1002 area

Tundra streams drain the Arctic coastal plain and the foothills to the south. They are generally small streams confined to a single meandering channel, although there may be braided sections in the larger streams (Craig and McCart 1975). The twenty tundra streams in this study all flow directly into coastal waters. Seven of these streams had been sampled previously (Table 4). Ninespine stickleback were captured in Fish Creek and the Niguanak River (West and Frugé 1989) and one Dolly Varden char was captured in Marsh Creek (Daum et al. 1984). Fish distribution in other tundra streams is more extensive where Arctic grayling, ninespine stickleback, and juvenile Dolly Varden char were captured in the Tamayariak River (Corning, unpublished report-a), Akutoktak River, and two smaller tundra streams flowing into the Okpilak River (Daum et al. 1984; West and Wiswar 1985; Wiswar et al. 1987; Wiswar 1991, 1992).

The objectives of this study in 1991 are to:

1. Determine spatial and temporal distribution of arctic fishes in rivers flowing through the 1002 area.
2. Collect baseline length and weight data on arctic fishes in the rivers.

Methods

Fish sampling in 20 tundra streams was conducted July 2-18, 1991. The number of samples sites ranged between one and five sites in the mainstem of rivers and one and three sites in tributary streams. Sites were resampled August 6-21 and September 11-24 to determine temporal changes in fish distribution. In September, only the Kogotpak River, Nataroarok, Marsh, and Carter creeks, and stream 7 were resampled due to an abbreviated schedule caused by weather. Sites were selected about 10 km apart or near the confluence of a major tributary.

Fish were collected with backpack electrofisher (Smith-Root Model 15A, 600 - 1100 volts, 60 - 90 pulses/s). Fish captured were counted and measured to the nearest mm fork length (FL) or total length for fish species with truncate or rounded caudal fins. Fish over 200 g were weighed to the nearest 10 g and fish less than 200 g to the nearest 0.1 g. Smaller fish (<200 mm FL) were placed in a solution of tricaine (MS 222) before measuring.

Dolly Varden char were categorized by life history stage (young of the year, juvenile, and adult) based on length and age information from Yoshihara (1972), McCart (1980), Smith and Glesne (1983), Daum et al. (1984), and West and Wiswar (1985). Dolly Varden char less than 71 mm FL were categorized as young of the year, those between 71 and 300 mm FL as juveniles, and char greater than 300 mm FL as adults.

Spatial and temporal fish distribution during July through September 1991 is presented by species and life history stage on maps of each river drainage. Tundra streams were assumed to contain no overwintering habitat and be absent of resident fish prior to breakup. Therefore, fish entered these streams from their mouth and migrated upstream. Fish captured at two consecutive sites were assumed to be distributed between those two sites.

Results

Fish distribution.—In tundra streams (Tables 5 and 6; Figure 1) juvenile Dolly Varden char (N = 104), juvenile (N = 3) and young of the year (N = 1) Arctic grayling, ninespine stickleback (N = 716), and fourhorn sculpin (N = 4) were captured.

Juvenile Dolly Varden char were captured in twelve streams but only in Nataroarok, Marsh, and Carter creeks were they captured during both July (N = 21) and August (N = 82). In August, juvenile char had a broader range of distribution. In September, juvenile Dolly Varden char was captured only in Nataroarok Creek (N = 1).

Ninespine stickleback were captured in 18 streams, but not during all sampling periods. They were found in 14 streams in July, 16 streams in August, and four streams in September. Fourhorn sculpin were captured in only stream 4 in July and that occurred near the mouth. Juvenile Arctic grayling were captured in Nataroarok Creek in August and young of the year were captured in the Kogotpak River in September.

Biological characteristics.—Based on the presence of parr marks and coloration, juvenile Dolly Varden char captured in July were either resident or presmolt, while some Dolly Varden char found in the six additional streams in August had completed parr-smolt transformation. Dolly Varden char captured ranged from 92 to 182 mm FL in July, and 63 - 237 mm FL in August (Table 7; Figure 3). Juvenile char weighed betweeen 2.4 and 143.0 g. Ninespine stickleback measured July through September ranged from 20 to 89 mm FL (Table 8).

Discussion

The presence of ninespine stickleback and Dolly Varden char in tundra streams in 1991 compares favorably with other studies (Ward and Craig 1974; Craig and Poulin 1975; Smith and Glesne 1982; West and Frugé 1989; Wiswar 1991, 1992; Corning, unpublished reports-a and b). Ninespine stickleback were ubiquitous as this species was captured in 18 of the 20 streams in this study and its presence is recorded in most of the other studies. Arctic grayling, although generally associated with tundra streams on the arctic coastal plain, were not captured but in one stream. This was probably due to the lack of overwintering habitat and salinities in the coastal waters acting as a migration barrier. The presence of fourhorn sculpin during this study at the mouth of one river was probably an incidental capture. Fourhorn sculpin may be found in the brackish, nearshore waters but is regarded as a marine species (Craig 1984). Fourhorn sculpin were also captured in a river-connected lake in the Canning River delta which would imply some use of freshwater habitats.

Juvenile Dolly Varden char were captured in twelve streams but only Nataroarok, Marsh, and Carter creeks were inhabited by juveniles during both July and August. In July, juvenile Dolly Varden char inhabited those tundra streams closest to the Aichilik River and both the tundra streams and Aichilik River flow into Beaufort Lagoon. The Aichilik River is a natal stream for Dolly Varden char. Mean salinity in Beaufort Lagoon was still less than 3‰ in mid-July 1991 (Fairbanks Fishery Resource Office, unpublished data). Assuming the Aichilik River to be the stream of origin, salinity apparently did not impede fish movement from the Aichilik River to the tundra streams during this time. Similarly, Dolly Varden char from the Hulahula River may have migrated to Nataroarak Creek. In August, juvenile Dolly Varden char were found in six other tundra streams.

To date, juvenile Dolly Varden have been captured in 19 (63%) of the 30 tundra streams sampled in the 1002 area (Tables 2, 6, and 7). Of the 30 tundra streams, 22 streams drain directly into coastal waters and juvenile char have been captured in 14 (64%) of them. Craig (1984, 1989) states that although tundra streams flowing directly into lagoons and coastal waters may support populations of Arctic grayling and ninespine stickleback, use by Dolly Varden char is incidental. While the 1991 study indicates tundra streams may further extend summer range for this species the extent of use and importance of this habitat is not known. Until such time when more information is available, as a conservation measure, rigorous sampling efforts should be conducted before site-specific development activities are permitted.

TABLE 4.—Documented species occurrence in tundra streams prior to 1991. DVC = Dolly Varden char, GR = Arctic grayling, NSB = ninespine stickleback, * = tundra stream resampled during this study (these streams flow into coastal waters with the exception of Itkilyariak Creek which is a tributary of the Sadlerochit River).

Stream	Date previously sampled	Species present
Tamayariak River	Jul 1982[a]; Jul-Sep 1988[b]	DVC, GR, NSB
Katakturuk River	Jul 1982; Jul-Aug 1989[c]; Jul-Sep 1990[d]	DVC, GR, NSB
Marsh Creek*	Jul 1983[e]; Jul 1986[f]	DVC
Carter Creek*	Aug 1982[a]; Jul 1983; Jul 1986	No fish documented
Sadlerochit River drainage		
middle tributary	Aug 1982[a]	GR
east side tributary	Aug 1982	No fish documented
Itkilyariak Creek*	Aug 1982	GR, DVC, NSB
Nataroarok Creek*	Jul 1987[g]	No fish documented
Okpilak River drainage		
lower tributary	Jul 1983; Jul 1989[h]; Jul-Sep 1990	DVC, GR, NSB
west side tributary	Jul, Aug 1989[h]; Jul-Sep 1990	DVC, GR, NSB
east side tributary 1	Jul 1989	No fish documented
east side tributary 2	Jul 1989	No fish documented
upper tributary	Jul-Sep 1990	GR
Akutoktak River	Jul 1974[i]; Aug 1982; Jul 1983; Jul, Aug 1989; Jul-Sep 1990	DVC, GR, NSB
Fish Creek*	Jul 1986	NSB
Jago River	Jul 1974; Jul 1982; Jul 1983; Jul-Sep 1989[c]; Jul-Sep 1990	DVC, NSB
Niguanak River*	Nov 1973[i]; Jul 1983	NSB
Angun River*	Jul 1983	No fish documented
Kogotpak River*	Nov 1973	No fish documented

[a] Smith and Glesne 1982
[b] Corning, unpublished report-a
[c] Corning, unpublished report-b
[d] Wiswar 1992
[e] Daum et al. 1984
[f] West and Frugé 1989
[g] Lyons and Elliott 1987
[h] Wiswar 1991
[i] Ward and Craig 1974

TABLE 5.—Summary of fish distribution in tundra streams in the 1002 area of the Arctic National Wildlife Refuge, July - September 1991. DVC = Dolly Varden char, GR Arctic grayling, FHS = fourhorn sculpin, NSB = ninespine stickleback, j = juvenile, yoy = young of the year, 0 = no fish captured, — = not sampled.

Stream	July	August	September
1	NSB	NSB	—
2	0	DVC j	—
Marsh Creek	DVC j	DVC j	0
Carter Creek	DVC j	DVC j	NSB
3	NSB	0	—
Kajutakrok Creek	0	NSB	—
Nataroarok Creek	DVC j, NSB	DVC j, NSB, GR j	DVC j, NSB
Fish Creek	NSB	DVC j, NSB	—
Niguanak Creek	NSB	NSB	—
4	NSB, FHS	NSB	—
John River	0	NSB	—
Kimikpaurauk River	NSB	DVC j, NSB	—
Siksik River	NSB	DVC j, NSB	—
Sikrelurak River	NSB	DVC j, NSB	—
Sikutaktuvik River	0	DVC j, NSB	—
Angun River	NSB	NSB	—
5	NSB	NSB	—
6	DVC j, NSB	NSB	—
Kogotpak River	DVC j, NSB	NSB	GR yoy, NSB
7	DVC j, NSB	NSB	NSB

TABLE 6.—Summary of capture information for fish caught in tundra streams in the 1002 area of the Arctic National Wildlife Refuge, July - September 1991. DVC = Dolly Varden char, FHS = fourhorn sculpin, GR = Arctic grayling, NSB = ninespine stickleback, j = juvenile, yoy = young of the year .

Stream	Dates sampled	Number of sites	Electrofishing effort (h)	Species and life history stage	N
1	Jul 13	3	1.5	NSB	4
	Aug 19	2	1.0	NSB	4
2	Jul 12	2	1.0		0
	Aug 18	2	1.0	DVC j	9
Marsh Creek	Jul 11	3	1.5	DVC j	1
	Aug 17-18	3	1.5	DVC j	3
	Sep 17-18	2	1.0		0
Carter Creek	Jul 10	3	1.5	DVC j	2
	Aug 16-17	3	1.5	DVC j	35
	Sep 17-18	2	0.6	NSB	2
3	Jul 7-9	3	1.5	NSB	4
	Aug 15	2	1.0		0
Kajutakrok Creek	Jul 7	1	0.5		0
	Aug 14	1	0.5	NSB	1
Nataroarok Creek	Jul 6-9	4	2.0	DVC j	8
				NSB	2
	Aug 14-15	3	1.5	DVC j	13
				GR j	3
				NSB	6
	Sep 17	3	1.5	DVC j	1
				NSB	2
Fish Creek	Jul 4-6	3	1.5	NSB	156
	Aug 6-10	3	1.5	DVC j	1
				NSB	18
Niguanak River	Jul 3-5	2	1.0	NSB	9
	Aug 10	3	1.5	NSB	3
4	Jul 4-6	2	0.9	NSB	30
				FHS	4
	Aug 10	2	0.9	NSB	18
John River	Jul 4	1	0.5		0
	Aug 9	1	0.5	NSB	3

TABLE 6.—Continued.

Stream	Dates sampled	Number of sites	Electrofishing effort (h)	Species and life history stage	N
Kimikpaurauk River	Jul 4	2	1.0	NSB	9
	Aug 9	2	1.0	DVC j	7
				NSB	45
Siksik River	Jul 4	2	1.0	NSB	5
	Aug 8	2	1.0	DVC j	4
				NSB	1
Sikrelurak River	Jul 3	2	0.9	NSB	3
	Aug 8-9	2	1.0	DVC j	3
				NSB	2
Sikutaktuvik River	Jul 4	1	0.5		0
	Aug 8-9	2	1.0	DVC j	7
				NSB	2
Angun River	Jul 3-4	2	1.0	NSB	7
	Aug 8	2	1.0	NSB	4
5	Jul 3	1	0.5	NSB	22
	Aug 7	1	0.5	NSB	40
6	Jul 2	2	1.0	DVC j	4
				NSB	39
	Aug 7	2	0.9	NSB	97
Kogotpak River	Jul 3	2	1.0	DVC j	3
				NSB	24
	Aug 7	2	1.0	NSB	115
	Sep 11	1	0.5	NSB	3
				GR yoy	1
7	Jul 2	2	1	DVC j	3
				NSB	16
	Aug 7	1	0.5	NSB	12
	Sep 11	1	0.5	NSB	8

TABLE 7.—Lengths and weights of Dolly Varden char captured in tundra streams in the 1002 area of the Arctic National Wildlife Refuge, July - September 1991.

		Fork length (mm)				Weight (g)			
Stream	Date	N	Mean	SD	Range	N	Mean	SD	Range
2	Aug 18	9	182.4	17.0	139 - 197	9	65.3	13.8	39.3 - 89.4
Marsh Creek	Jul 11	1	182			1	57.9		
	Aug 17	1	191			1	77.0		
Carter Creek	Jul 10	1	170			1	58.3		
	Aug 16-17	15	187.1	14.5	165 - 211	14	70.8	16.2	49.2 - 98.4
Nataroarok Creek	Jul 6-7	4	109.3	13.7	92 - 130	4	13.2	4.0	8.6 - 19.6
	Aug 14-15	9	106.3	29.2	63 - 151	9	15.9	11.3	2.4 - 37.9
	Sep 17	1	127			1	22.5		
Fish Creek	Aug 10	1	186			1	73.6		
Kimikpaurauk River	Aug 9	6	185.0	11.3	170 - 200	6	63.0	9.6	49.5 - 74.7
Siksik River	Aug 8	3	185.0	18.4	159 - 198	3	61.1	10.8	48.4 - 74.8
Sikrelurak River	Aug 8-9	2	212.5	6.5	206 - 219	2	122.9	20.1	102.8 - 143.0
Sikutaktuvik River	Aug 8-9	6	201.7	24.3	163 - 237	5	83.9	31.5	37.2 - 133.7
6	Jul 2	1	116			1	20.4		
Kogotpak River	Jul 3	3	108.3	7.6	102 - 119	3	11.2	2.4	8.2 - 14.2
7	Jul 2	2	135.0	19.0	116 - 154	2	21.9	10.3	11.6 - 32.2

TABLE 8.—Lengths of ninespine sticklebacks captured in tundra streams in the 1002 area of the Arctic National Wildlife Refuge, July - September 1991.

Stream	Date of capture	N	Fork length (mm) Mean	SD	Range
1	Jul 13	2	35.5	1.5	34-37
	Aug 19	1	65		
3	Jul 9	3	53.0	3.7	48-57
Nataroarak Creek	Jul 7	1	48		
	Aug 14-15	4	67.5	5.1	63-76
	Sep 17	2	43.2	20.5	20-73
Fish Creek	Jul 6	51	38.7	6.7	28-54
	Aug 6-10	13	57.5	6.7	47-69
Niguanak River	Jul 3-5	4	48.0	11.4	37-67
	Aug 10	3	66.3	11.3	51-78
4	Jul 4	29	46.7	8.7	32-65
	Aug 10	8	54.4	9.5	43-72
John River	Aug 9	3	65.3	6.0	57-71
Kimikpaurauk River	Jul 4	6	39.5	5.7	32-48
	Aug 9	23	62.4	14.2	39-89
Siksik River	Jul 4	2	44.5	1.5	43-46
Sikrelurak River	Jul 3	3	46.3	6.3	40-55
	Aug 9	2	69.0	8.0	61-77
Sikutaktuvik River	Aug 9	2	72.5	10.5	62-83
Angun River	Jul 3	1	55		
	Aug 8	3	50.7	4.2	45-55
5	Jul 3	6	54.8	7.4	43-68
	Aug 7	22	66.6	7.0	55-79
6	Jul 2	19	47.2	13.2	30-74
	Aug 7	55	68.6	8.0	51-85
Kogotpak River	Jul 3	14	53.4	12.0	31-67
	Aug 7	52	65.3	6.2	51-83
	Sep 11	3	37.0	18.1	20-62
7	Jul 2	7	48.3	10.0	34-63
	Aug 7	5	57.8	4.3	54-64
	Sep 11	7	70.1	8.4	60-87

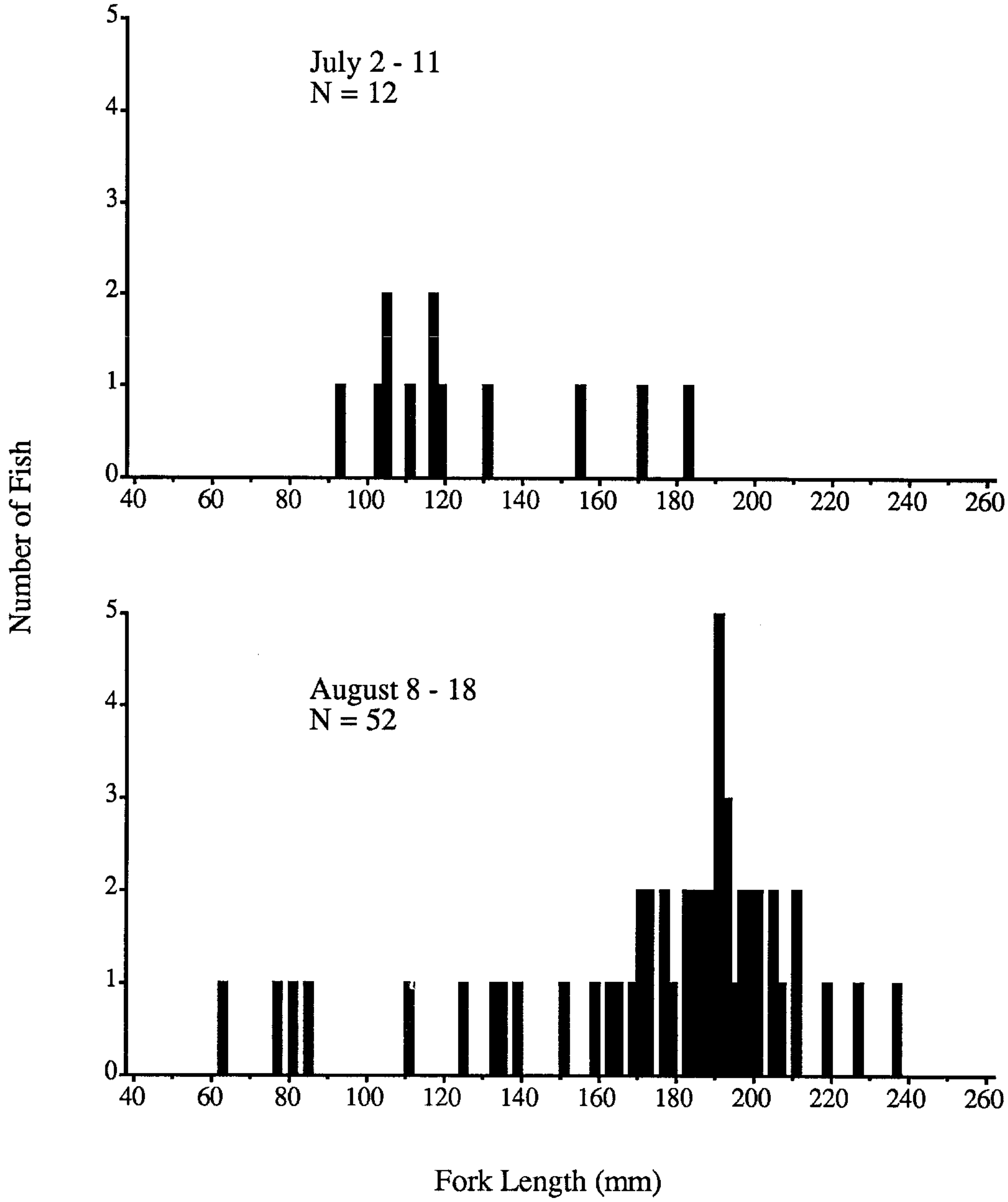


FIGURE 3.—Length-frequency of Dolly Varden char captured in tundra streams in the 1002 area of the Arctic National Wildlife Refuge during July and August 1991.

Sadlerochit River drainage

In the 1002 area, the Sadlerochit River drainage includes the mainstem Sadlerochit River, Itkilyariak Creek, their tributaries, and Sadlerochit Spring (Figure 1). Kekiktuk River is the outlet of lakes Schrader and Peters in the upper Sadlerochit drainage. Juvenile and adult Arctic grayling are distributed throughout the mainstem Sadlerochit River in June, July, and August (Ward and Craig 1974; Smith and Glesne 1983). Dolly Varden char, pink salmon *Oncorhynchus gorbuscha*, and young of the year Arctic grayling have been captured in the mainstem in July and young of the year Arctic grayling were found in one tributary (Smith and Glesne 1983). Although anadromous Dolly Varden char have been captured, there is no evidence that the Sadlerochit River supports a spawning population (Smith and Glesne 1983).

Resident Dolly Varden char and three life history stages (young of the year, juvenile, and adult) of Arctic grayling were captured in Itkilyariak Creek and a lower tributary during a survey in August 1982 (Smith and Glesne 1983). Ninespine stickleback were captured in lower Itkilyariak Creek. Fall movements of adult Arctic grayling from Itkilyariak Creek to potential overwintering areas have been documented using radio telemetry during August through October 1984 and August through December 1985 (West and Wiswar 1985; Wiswar et al. 1987). Arctic grayling were relocated in the mainstem Sadlerochit River, Kekiktuk River, and lakes Peters and Schrader.

Sadlerochit Spring supports a resident population of Dolly Varden char which are distributed throughout the spring above the *aufeis* (overflow icing) area (Craig 1977). The *aufeis* area is considered a migration barrier. Juvenile Arctic grayling were also found in the spring (Craig 1977).

The objectives of this study in 1991 are to:

1. Determine spatial and temporal distribution of arctic fishes in the Sadlerochit drainage within and flowing through the 1002 area.
2. Determine length frequency and length-weight relationship for Dolly Varden char and Arctic grayling and age structure for Arctic grayling.
3. Collect and measure young of the year Arctic grayling from the Akutoktak River and compare with young of the year from the Sadlerochit drainage.

Methods

Fish sampling in the Sadlerochit River drainage was conducted July 2-18, 1991. Sites were resampled August 6-21 and September 11-24 to determine temporal changes in fish distribution. Kekiktuk River was sampled on September 24. Sites were selected about 10 km apart or near the confluence of a major tributary.

Fish were collected with backpack electrofisher (Smith-Root Model 15A, 600 - 1100 volts, 60 - 90 pulses/s) and hook and line. Visual observations of fish were recorded.

Fish captured were counted and measured to the nearest mm fork length (FL). Fish over 200 g were weighed to the nearest 10 g and fish less than 200 g to the nearest 0.1 g. Smaller fish (<200 mm FL) were placed in a solution of tricaine (MS 222) before measuring.

Regression of $\log_{10}$ transformations of length and weight was used to describe length-weight relationships (Ricker 1975). Slopes and intercepts of regression lines were compared using dummy variables (Kleinbaum and Kupper 1978) and data were pooled when no significant difference was detected ($P > 0.05$) in the weight-length relationships.

Ages of Arctic grayling were estimated from scales. Scales were removed from the left side of the fish between the lateral line and posterior dorsal insertion. Scales were pressed on triacetate slides and viewed through a microfiche reader. All scales were read by two independent readers. When disagreement occurred, scales were read by a third person. Mean length at age data were calculated for Arctic grayling from Itkilyariak Creek and the Sadlerochit River. Inadequate sample size precluded using data from other locations.

Arctic grayling were categorized by life history stage (young of the year, juvenile, and adult) based on length and age information from Craig and Poulin (1975), Smith and Glesne (1983), Daum et al. (1984), Wiswar (1991, 1992), Corning (unpublished report-a), and this study. Arctic grayling less than 82 mm FL were categorized as young of the year, those between 82 and 285 mm FL were juveniles, and Arctic grayling greater than 285 mm FL were adults.

Resident Dolly Varden char in Sadlerochit Spring are a dwarf population (Craig 1977) and may be found in Itkilyariak Creek and the Sadlerochit River. Because there is little information on their population structure, no attempt was made to categorize this population by life history stage in the Sadlerochit River drainage.

Objective 3 was added to the study after the August 14, 1991 sampling in Itkilyariak Creek. It was noted then, that young of the year Arctic grayling appeared to be smaller than young of the year captured in the Akutoktak River during August the previous two years (1989 and 1990). Therefore, to determine if the presence of smaller fish in 1991 was a regional phenomena or restricted to Itkilyariak Creek, young of the year from the Akutoktak River were collected on August 16 and 17, 1991 and lengths were compared (t-test, $P < 0.05$; Zar 1984).

Results

Sadlerochit River fish distribution.—In the mainstem Sadlerochit River, Dolly Varden char and all three life history stages of Arctic grayling were captured (Table 9). Dolly Varden char captured in July (N = 6) and August (N = 9) were in the lower mainstem (site SM 1) and between 35 - 45 km upriver (sites SM 3 and 4; Figure 4). In September, Dolly Varden char (N = 6) were located in the mainstem between 45 and 55 km upriver. Adult Arctic grayling were captured at two mainstem sites in July (N = 26) and three sites in August (N = 5; Figure 5). Juvenile Arctic grayling were captured in the mainstem only in August (N = 4; Figure 6). Young of the year Arctic grayling were captured in August (N = 1) at one mainstem site (site SM 4) and in September (N = 23) between 45 and 55 km upriver (sites SM 4 and 9; Figure 7).

Two tributaries on the east side of the Sadlerochit River were sampled in July, but only the lower tributary was sampled in August and September. In the upper tributary (site ST 8), one adult Arctic grayling was found in July (Figure 5). In the lower tributary (sites ST 5 and 6), Dolly Varden char, Arctic grayling, and ninespine stickleback were captured. Dolly Varden char were captured only in September (site ST 5; N = 2; Figure 4). Adult (N = 4) and juvenile (N = 1) Arctic grayling were captured only in July (Figures 5 and 6). In September, young of the year Arctic grayling (N = 8) were captured in a lower reach of the tributary (site ST 5; Figure 7). Ninespine stickleback were captured in the lower tributary in both August (N = 3) and September (N = 1).

Juvenile (N = 7) and adult (N = 1) Arctic grayling were also captured at one site in the Kekiktuk River in September (Figure 8). No young of the year were captured.

Sadlerochit River biological characteristics.—Dolly Varden char captured in the mainstem and tributary ranged from 93 to 233 mm FL (Table 10). No young of the year or anadromous adult Dolly Varden char were captured.

Adult Arctic grayling captured in the mainstem and tributary were 304 - 338 mm FL (Table 11; Figure 9). Juvenile and young of the year Arctic grayling ranged from 86 to 242 mm FL and 32 - 47 mm FL, respectively.

Itkilyariak Creek fish distribution.—Stream discharge in Itkilyariak Creek was intermittent above the confluence of Sadlerochit Spring (near site IM 2; Figure 10) after late June and was not sampled. The lower tributary (site IT 4) was sampled only in August because of low discharge in July and high discharge in September. Dolly Varden char and all life history stages of Arctic grayling were captured in either the lower Itkilyariak Creek or two of its tributaries (Table 9). In the mainstem, Dolly Varden char were captured July through September (N = 15) and adult Arctic grayling were captured or observed in July and August (N = 9; Figures 10 and 11). Young of the year Arctic grayling were captured only in August (N = 3; Figure 12). Juvenile Arctic grayling were not captured.

In the upper tributary (sites IT 5 - 7), Dolly Varden char and Arctic grayling were found throughout the stream but their distribution was not uniform. Dolly Varden char were captured in July (N = 4) and August (N = 6; Figure 10). Adult Arctic grayling were captured and observed (N = 59) at all three sites but only in July (Figure 11). Juvenile Arctic grayling (N = 8) were found in both July and August but not at all sites (Figure 13). Young of the year Arctic grayling (N = 83) were located at the two lower sites (IT 5 and 6) only in August (Figure 12).

In the lower tributary (site IT 4) in August, Dolly Varden char (N = 1) and juvenile Arctic grayling (N = 4) were captured.

Itkilyariak Creek biological characteristics.—Dolly Varden char captured in the mainstem Itkilyariak Creek and tributary streams were 93 - 203 mm FL and weighed between 9.2 and 75.0 g (Table 10). Adult Arctic grayling captured in Itkilyariak Creek in July and August ranged from 304 to 369 mm FL and weighed between 304 and 369 g (Table 11; Figure 9). Juveniles were from 125 to 193 mm FL. Young of the year captured in one of the tributary streams on August 11 were 24 - 32 mm FL, while at a site in the lower mainstem Itkilyariak Creek on August 21, young of the year were 11 - 14 mm FL (Figure 14).

Sadlerochit Spring fish distribution.—Resident Dolly Varden char were captured in Sadlerochit Spring at an upper site (Sp 1) in August (N = 76) and a lower site (Sp 2) in September (N = 68; Table 9; Figure 10). The spring was not sampled in July.

Sadlerochit Spring biological characteristics.—Dolly Varden char in Sadlerochit Spring measured 68 - 184 mm FL and weighed between 3.5 and 75.7 g (Table 10; Figure 15). There was no significant difference ($P > 0.50$) in the weight-length relationship between months. The relationship for the pooled data is presented in Figure 16.

Age of Arctic grayling.—Ages estimated from scales of Arctic grayling from Itkilyariak Creek and the Sadlerochit River ranged from 1 to 8 years (Table 12). All adult size fish were 4 years old and greater.

Comparison with Akutoktak River young of the year Arctic grayling.— Young of the year Arctic grayling from the Akutoktak River were measured on August 16 and 17, 1991 ranged from 30 to 50 mm

FL ($N = 53$, $\bar{x} = 41.5$ mm FL, $SD = 4.9$). When compared with young of the year from Itkilyariak Creek captured on August 11 and 14, Itkilyariak Creek Arctic grayling were significantly smaller ($P < 0.0001$) than those fish from the Akutoktak River.

Discussion

Sadlerochit River drainage.—The summer spatial distribution of Dolly Varden char and Arctic grayling in the Sadlerochit River drainage in 1991 was similar to that documented in 1982 by Smith and Glesne (1983). Dolly Varden char and Arctic grayling were found in the mainstem and tributaries of the Sadlerochit River and Itkilyariak Creek. Dolly Varden char captured in the drainage probably dispersed from Sadlerochit Spring. Adult Arctic grayling are found in the 1002 portion of the drainage primarily June through August, while young of the year occur in August and September.

Distribution of juvenile Arctic grayling in the Sadlerochit River drainage and other rivers in the 1002 area has not been adequately described. Catches of juveniles have been disproportionately low to that of adults or length classes have been missing (Smith and Glesne 1983; Daum et al. 1984; Wiswar 1991, 1992; Corning, unpublished report-a). It is possible that lakes Peter and Schrader are used as rearing habitat for a major portion of the juvenile population in this drainage. Adult Arctic grayling captured in Itkilyariak Creek during summer use these lakes to overwinter (West and Wiswar 1985; Wiswar et al. 1987).

Mean length and frequency distribution of adult Arctic grayling from Itkilyariak Creek in 1991 was similar to that of 1982, except in 1982, there were more individual fish larger than 370 mm FL (Smith and Glesne 1983).

The use of scales to determine age of Arctic grayling in the Sadlerochit River drainage may tend to underestimate the true age. In this study, mean lengths at age determined from scales were greater than lengths from comparable aged fish where ages were estimated from otoliths in 1982 (Smith and Glesne 1983). Also, the oldest age fish in 1991 was 8 years old whereas Smith and Glesne (1983) reported Arctic grayling ages to 13 years. Other studies have shown that scales tend to underestimate age of Arctic grayling when compared to otoliths, vertebrae, and fin rays especially for older fish (Craig and Poulin 1975; Beamish and McFarlane 1987; Merritt and Fleming 1991; Wiswar 1992). Validation of age using any of the above mentioned structures has not been determined for Arctic grayling; therefore conclusions inferred from age estimates should be viewed with conjecture.

Young of the year in Itkilyariak Creek were first captured in August of 1991 which is later than what has been observed in nearby drainages. In the Akutoktak (Wiswar 1991, 1992), Tamayariak (Corning, unpublished report-a), and headwater streams in the Sagavanirktok and Atigun (Elliott 1982) rivers, young of the year were first captured in late June or early July. Although the causes are unknown, possible explanations may include a later migration by adult Arctic grayling to spawning areas or slower development of young of the year in Itkilyariak Creek.

Also noted in August 1991 was that young of the year Arctic grayling captured in Itkilyariak Creek were smaller than those captured on about the same time period in the Akutoktak River in 1989 and 1990 (Wiswar 1991, 1992). Small size young of the year Arctic grayling in Itkilyariak Creek captured in early August 1982 (Fairbanks Fishery Resource Office, unpublished data) were similar in length to those fish in 1991. This supports the hypothesis that 1991 was not an anomaly and that either timing of adult migration and spawning is later and/or young of the year growth is slower in Arctic grayling from Itkilyariak Creek.

Fish migration, spawning, development, and growth is generally regarded as temperature dependent (Lagler et al. 1962) and may explain the size difference of young of the year Arctic grayling from the two rivers. Mean daily water temperatures in Itkilyariak Creek in June (4.4° C) and July (8.6° C) 1991 (Lyons and Trawicki 1992) were slightly cooler (although not statistically different; $P = 0.065$, Mann-Whitney test; Zar 1984) than water temperatures in the Akutoktak River (5.6° and 9.3° C, respectively).

TABLE 9.—Summary of gear used and capture information for fish caught in the Sadlerochit River drainage, July - September 1991. DVC = Dolly Varden char, GR = Arctic grayling, NSB = ninespine stickleback, a = adult, j = juvenile, yoy = young of the year.

Dates sampled	Number of sites	Gear type	Effort (h)	Species and life history stage	N
		Sadlerochit River mainstem			
Jul 10 - 17	5	Electrofisher	2.1	DVC	6
				GR a	2
Jul 6	1	Hook and line	3.0	GR a	24
Aug 10 - 14	3	Electrofisher	2.0	DVC	9
				GR a	5
				GR j	4
				GR yoy	1
Sep 18 - 19	2	Electrofisher	0.9	DVC	6
				GR yoy	23
		Sadlerochit River upper tributary			
Jul 17	1	Electrofisher	0.5	GR a	1
		Sadlerochit River lower tributary			
Jul 16	3	Electrofisher	1.5	GR a	4
				GR j	1
Aug 12 - 14	3	Electrofisher	1.2	NSB	3
Sep 18 - 19	3	Electrofisher	1.5	DVC	2
				GR yoy	8
				NSB	1
		Kekiktuk River			
Sep 24	1	Electrofisher	0.5	GR a	1
				GR j	7
		Itkilyariak Creek mainstem			
Jul 15 - 18	3	Electrofisher	1.5	DVC	1
				GR a	4
	1	Hook and line	1.2	GR a	2
	1	Visual		GR a	1
Aug 11 - 21	3	Electrofisher	1.5	DVC	13
				GR a	2
				GR yoy	3
Sep 18	1	Electrofisher	0.5	DVC	1

TABLE 9.—Continued.

Dates sampled	Number of sites	Gear type	Effort (h)	Species and life history stage	N
		Itkilyariak Creek upper tributary			
Jul 15 - 18	3	Electrofisher	1.5	DVC	4
				GR a	36
				GR j	7
	3	Hook and line	2.0	GR a	12
	3	Visual		GR a	11
Aug 11 - 14	3	Electrofisher	1.6	DVC	6
				GR j	1
				GR yoy	83
Sep 18	2	Electrofisher	1.0		0
		Itkilyariak Creek lower tributary			
Aug 12	1	Electrofisher	0.5	DVC	1
				GR j	4
		Sadlerochit Spring			
Aug 11	1	Electrofisher	0.5	DVC	76
Sep 19	1	Electrofisher	0.5	DVC	68

TABLE 10.—Lengths and weights of Dolly Varden char captured in the Sadlerochit River drainage, July - September 1991.

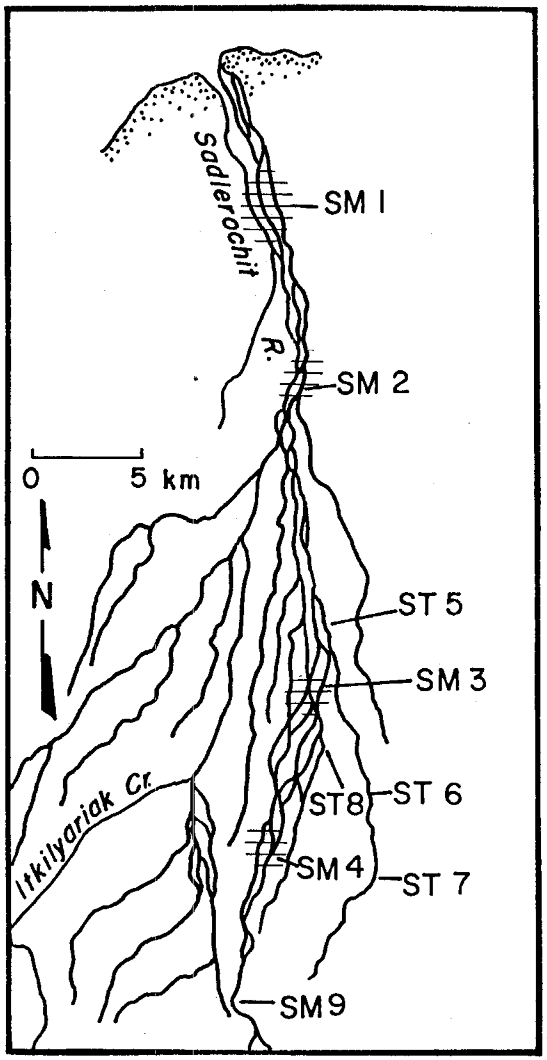
Dates of capture	Fork length (mm) N	Mean	SD	Range	Weight (g) N	Mean	SD	Range
				Sadlerochit River and lower tributary				
Jul 14 - 17	3	125.0	31.8	102-170	3	24.1	25.6	5.8-60.3
Aug 12 - 14	6	171.0	37.1	124-233	3	69.9	34.9	26.2-111.7
Sep 18 - 19	5	148.8	50.2	93-224	3	45.0	44.9	7.2-108.1
				Itkilyariak Creek and tributaries				
Jul 15 - 18	3	119.6	24.9	93-153	3	20.1	11.4	9.2-35.8
Aug 11 - 21	18	138.3	30.2	105-203	14	25.9	15.3	14.3-75.0
Sep 18	1	167			1	58.3		
				Sadlerochit Spring				
Aug 11	44	113.6	30.9	68-184	44	19.5	16.1	3.5-75.7
Sep 19	23	102.1	23.4	74-157	23	13.5	10.6	4.5-44.5

TABLE 11.—Lengths and weights of Arctic grayling captured in the Sadlerochit River drainage, July - September 1991. yoy = young of the year.

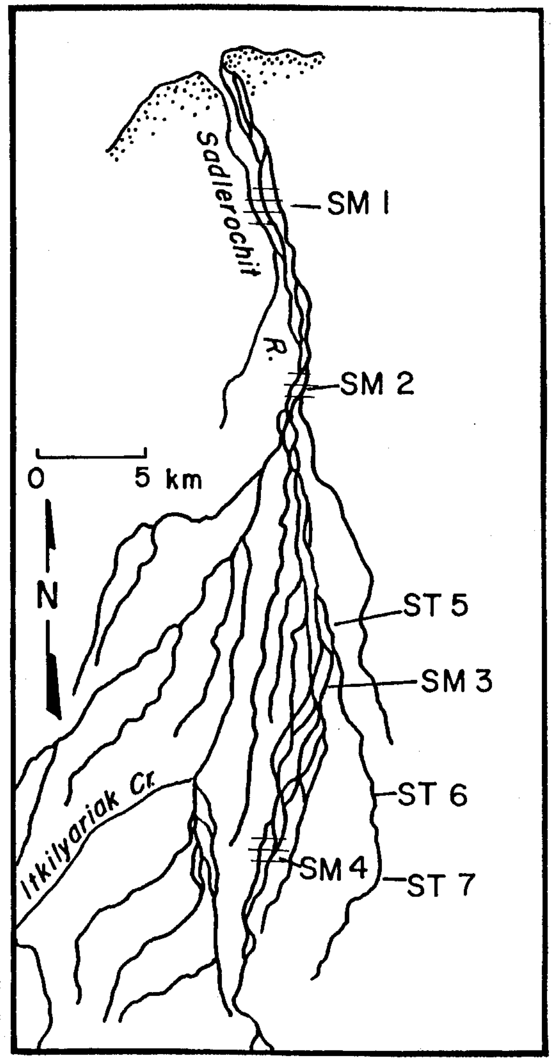
		Fork length (mm)				Weight (g)			
Dates of capture	Life history stage	N	Mean	SD	Range	N	Mean	SD	Range
					Sadlerochit River and lower tributary				
Jul 14 - 17	adult	3	332.3	7.3	322-338	3	372.7	26.6	350-410
	juvenile	1	153			1	19.0		
Aug 12 - 14	adult	5	315.0	10.0	304-332	5	359.8	31.4	299-380
	juvenile	4	135.0	63.2	86-242	4	47.9	65.7	5.8-161.4
	yoy	1	33						
Sep 19	yoy	10	41.4	4.4	32-47				
					Kekiktuk River				
Sep 24	juvenile	2	96.0	0.0		2	8.8	0.3	8.5-9.0
					Itkilyariak Creek and tributaries				
Jul 15 - 18	adult	24	335.3	17.7	304-369	24	421.5	52.6	350-575
	juvenile	3	141.0	10.7	129-155	3	27.5	5.7	21.2-35.1
Aug 11 - 14	adult	1	335			1	450		
	juvenile	5	171.2	23.8	125-193	5	68.8	26.7	19.3-98.7
	yoy	38	27.4	1.7	24-32				
Aug 21	yoy	3	12.3	1.3	11-14				

TABLE 12.—Length and weight at age of Arctic grayling from the Sadlerochit River drainage, July and August 1991. Ages estimated from scales.

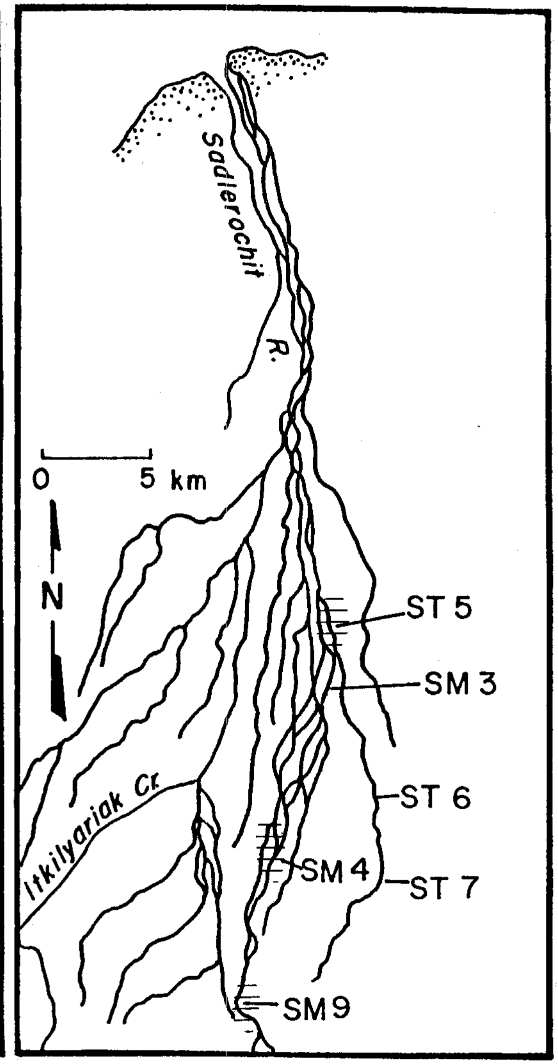
			Fork length (mm)			Weight (g)		
Age	Sampling period	N	Mean	SD	Range	Mean	SD	Range
1	Jul	3	141.0	10.7	129-155	27.5	5.7	21.2-35.1
	Aug	4	105.8	17.4	86-125	12.4	5.9	5.8-19.3
	Sep	2	96.0	0		8.8	0.3	8.5-9.0
2	Jul	1	153			19.0		
	Aug	4	182.8	6.5	175-193	81.2	11.0	68.8-98.7
3		0						
4	Jul	2	328.0	24.0	304-352	405.0	55.0	350-460
	Aug	1	242			161.4		
5	Jul	1	368			575		
6	Jul	5	327.6	10.0	311-338	412.0	19.4	380-440
7	Jul	11	338.3	17.0	322-369	407.7	46.5	350-505
	Aug	3	319.3	12.0	306-335	403.3	33.0	380-450
8	Jul	4	328.3	6.1	322-337	400.8	29.1	358-440
	Aug	2	324.0	8.0	316-332	370.0	10.0	360-380



July 10 - 17, 1991

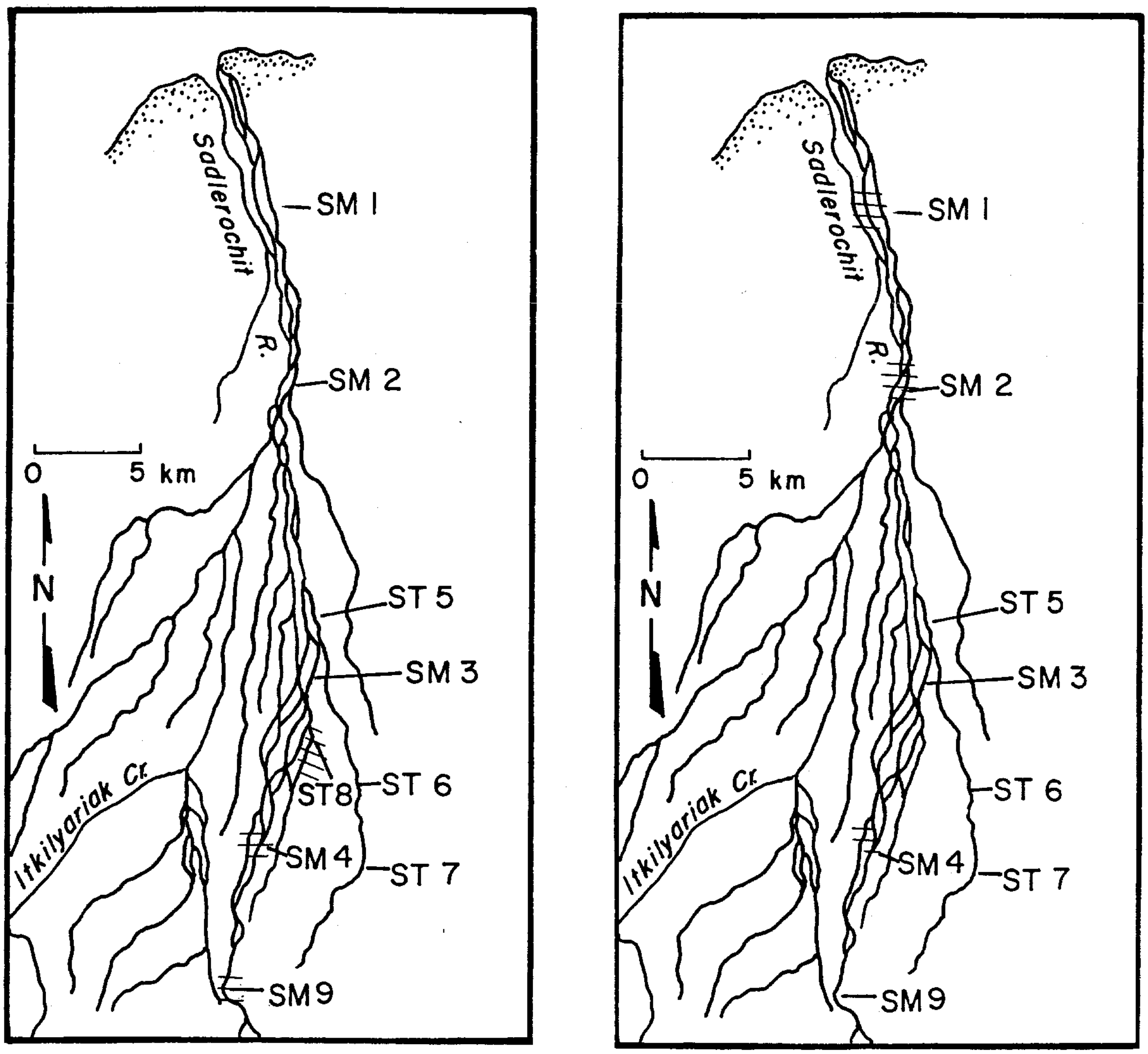


August 10 - 14, 1991



September 18 - 19, 1991

FIGURE 4.—Distribution of Dolly Varden char (hatch marked) in the Sadlerochit River during July - September 1991. SM = mainstem sample site, ST = tributary site.



July 6 - 17, 1991　　　　August 10 - 14, 1991

FIGURE 5.—Distribution of adult Arctic grayling (hatch marked) in the Sadlerochit River during July and August 1991. SM = mainstem sampling site, ST = tributary site.

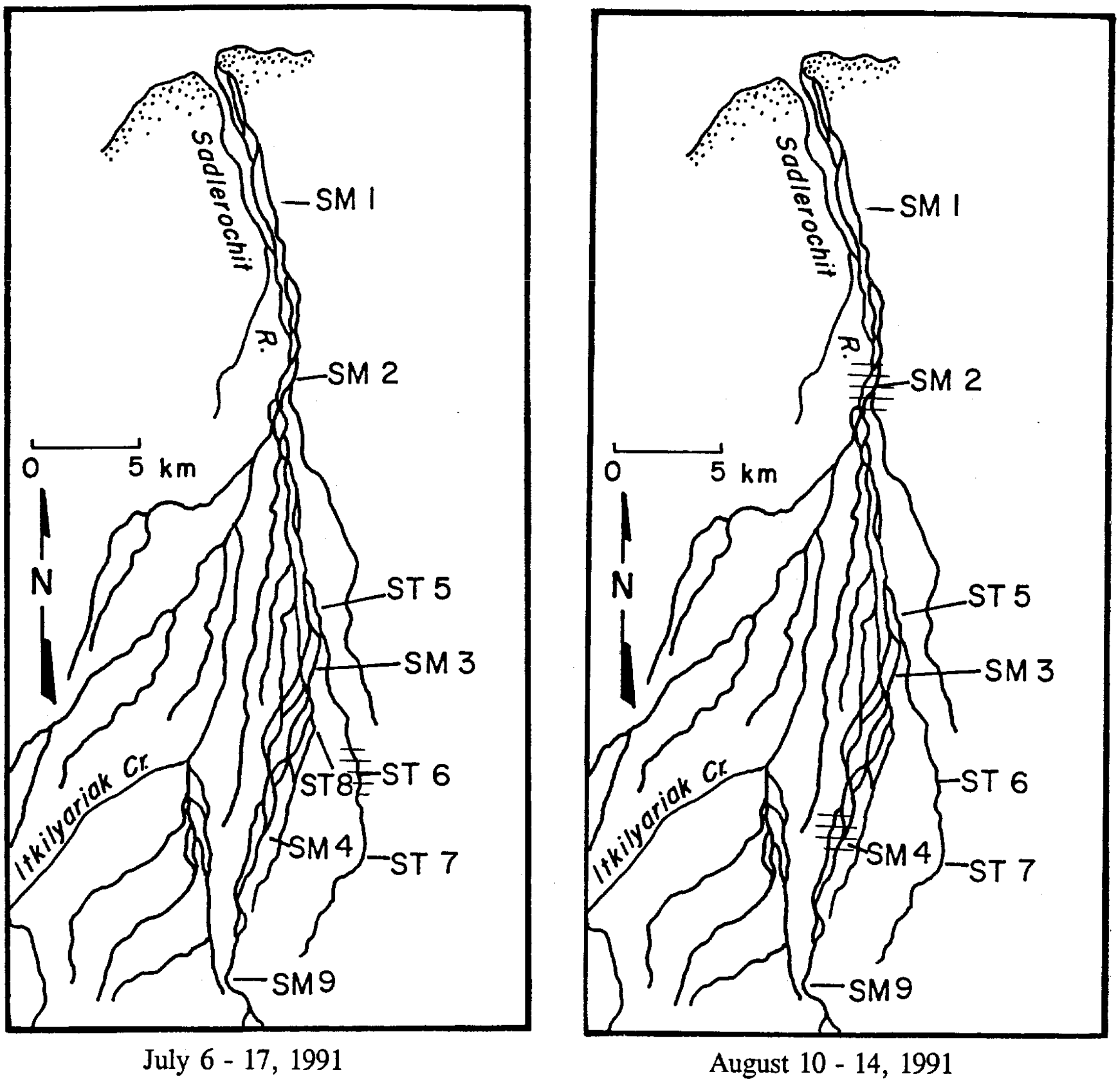
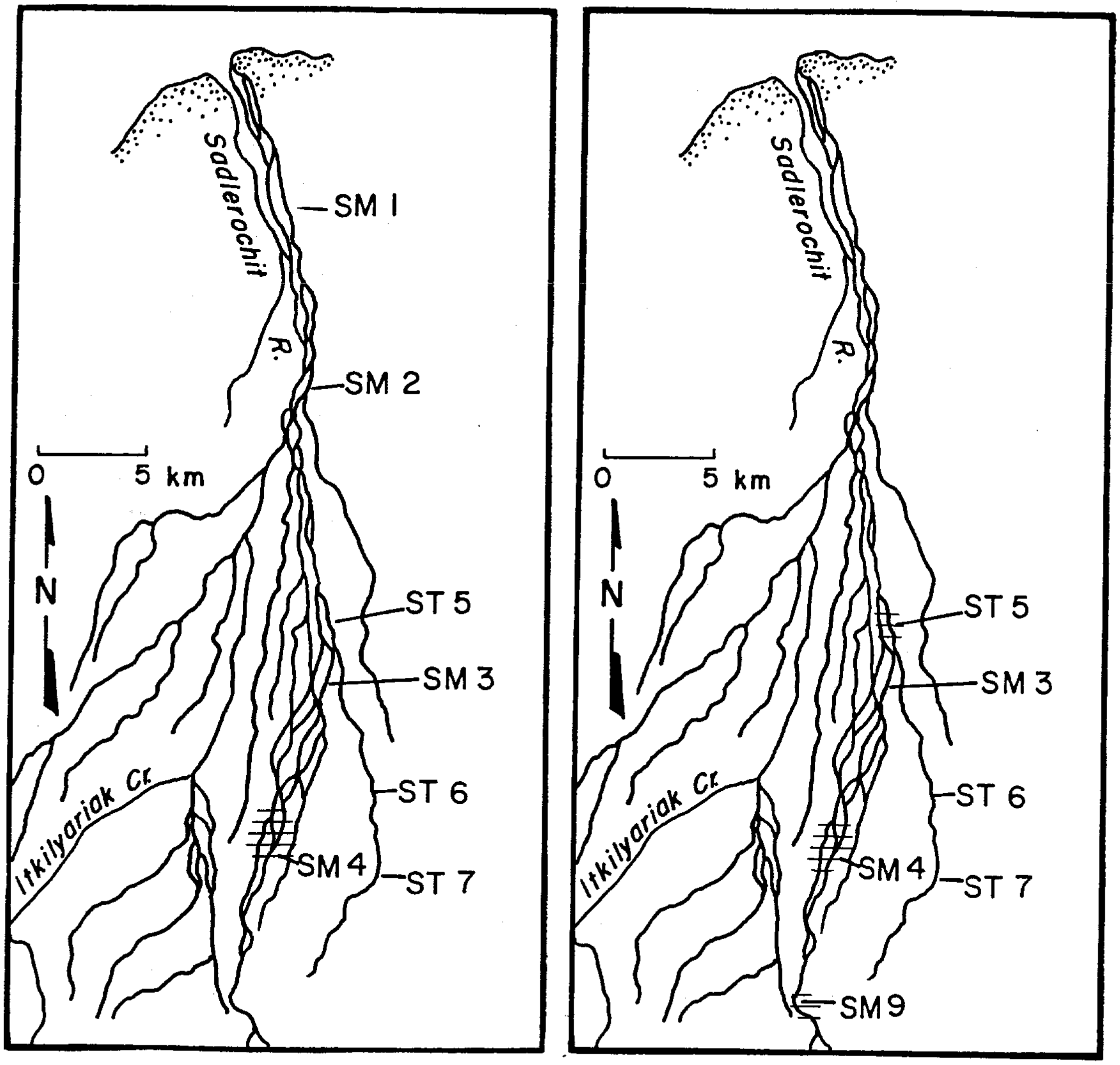


FIGURE 6.—Distribution of juvenile Arctic grayling (hatch marked) in the Sadlerochit River during July and August 1991. SM = mainstem sampling site, ST = tributary site.



August 10 - 14, 1991 September 18 - 19, 1991

FIGURE 7.—Distribution of young of the year Arctic grayling (hatch marked) in the Sadlerochit River during August and September 1991. SM = mainstem sampling site, ST = tributary site.

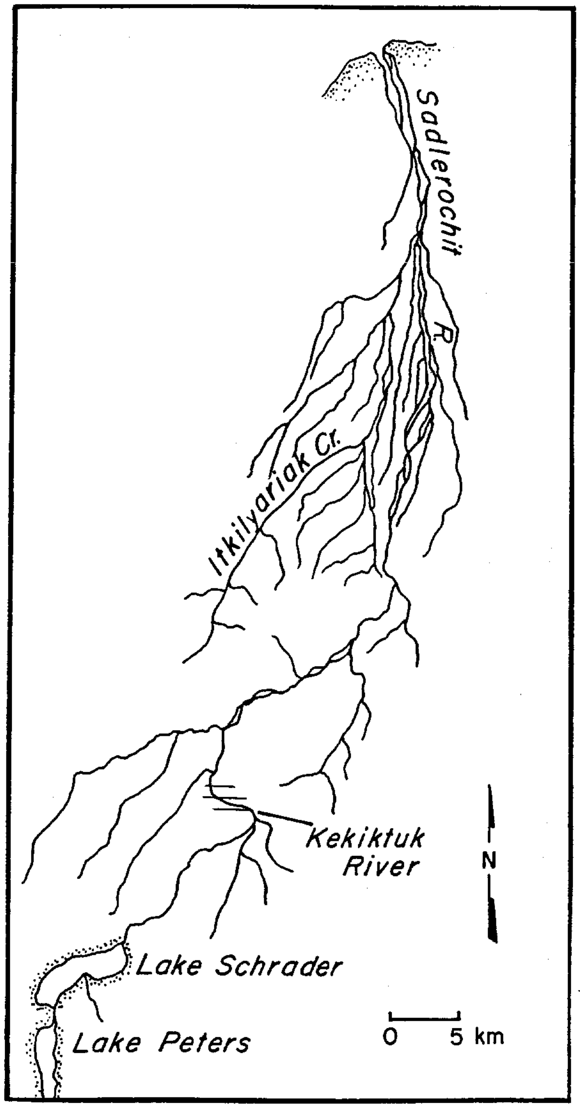


FIGURE 8.—Location of adult and juvenile Arctic grayling captured (hatch marked) in the Kekiktuk River on September 24, 1991.

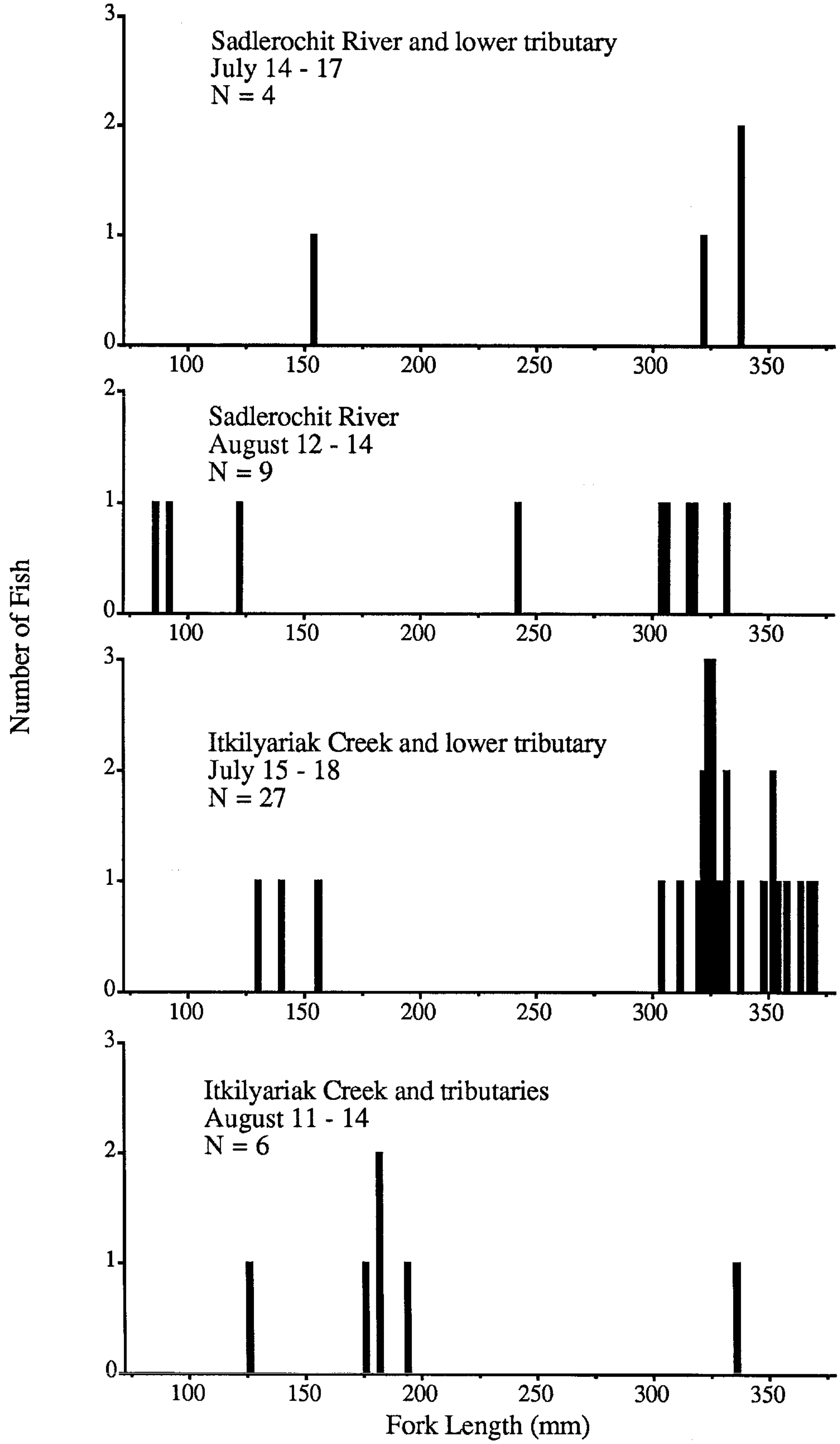
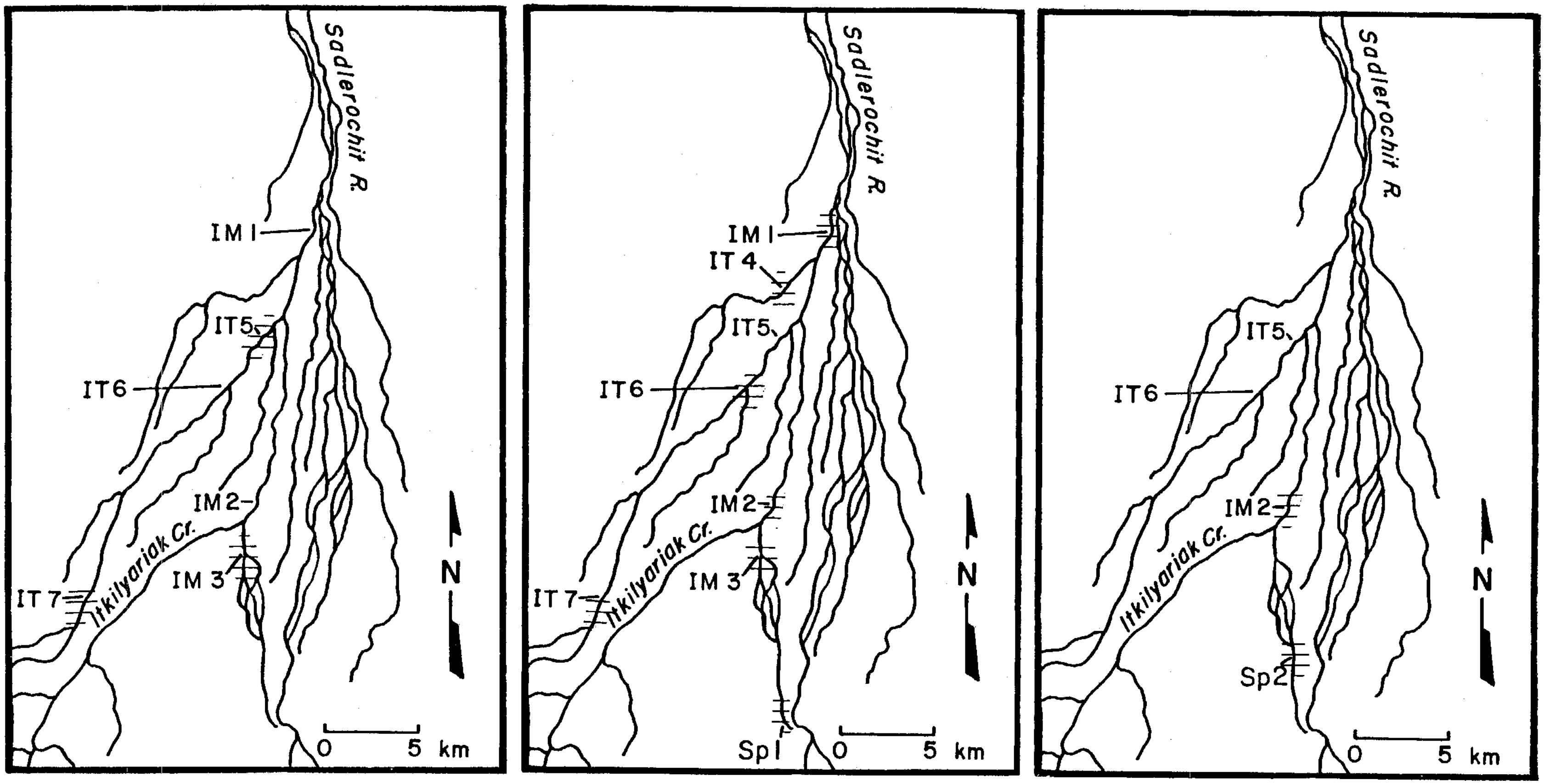


FIGURE 9.—Length-frequency of juvenile and adult Arctic grayling captured in the Sadlerochit River drainage during July and August 1991.



July 15 - 18, 1991   August 11 - 21, 1991   September 18 - 19, 1991

FIGURE 10.—Distribution of Dolly Varden char (hatch marked) in Itkilyariak Creek during July - September 1991 and Sadlerochit Spring during August and September 1991. IM = mainstem sample site, IT = tributary site, Sp = Sadlerochit Spring site.

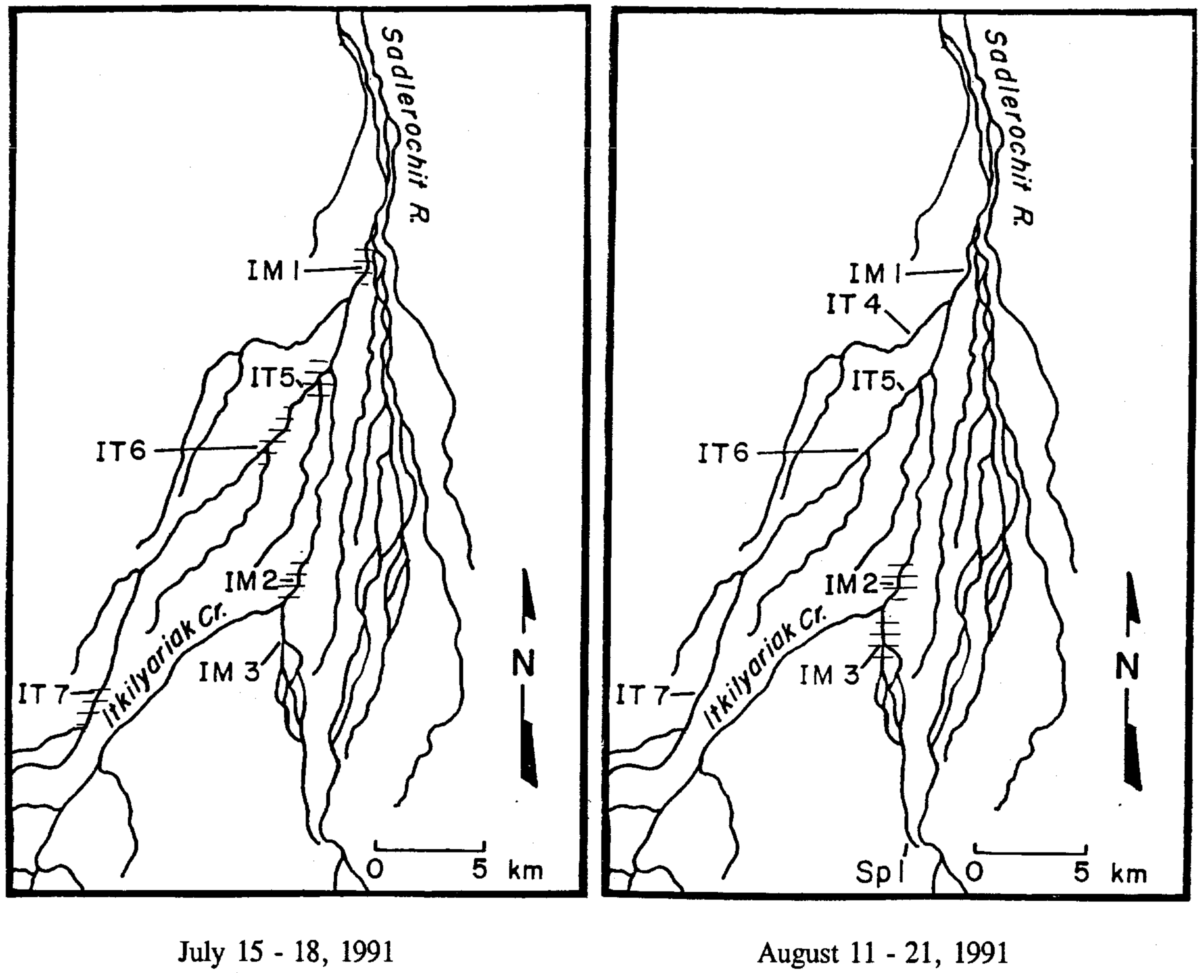


FIGURE 11.—Distribution of adult Arctic grayling (hatch marked) in Itkilyariak Creek during July and August 1991. IM = mainstem sampling site, IT = tributary site, Sp = Sadlerochit Spring site.

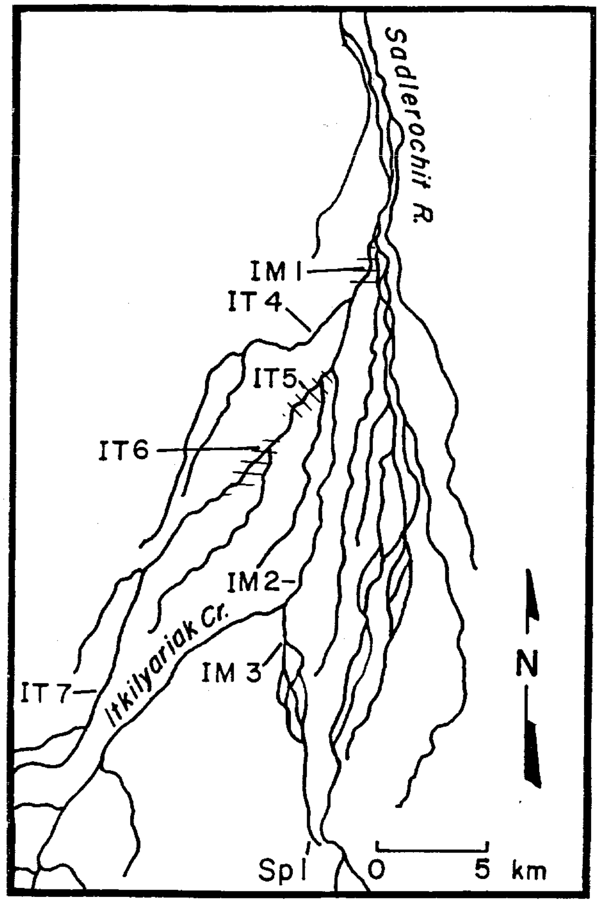


FIGURE 12.—Distribution of young of the year Arctic grayling (hatch marked) in Itkilyariak Creek between August 11 - 21, 1991. IM = mainstem sampling site, IT = tributary site, Sp = Sadlerochit Spring site.

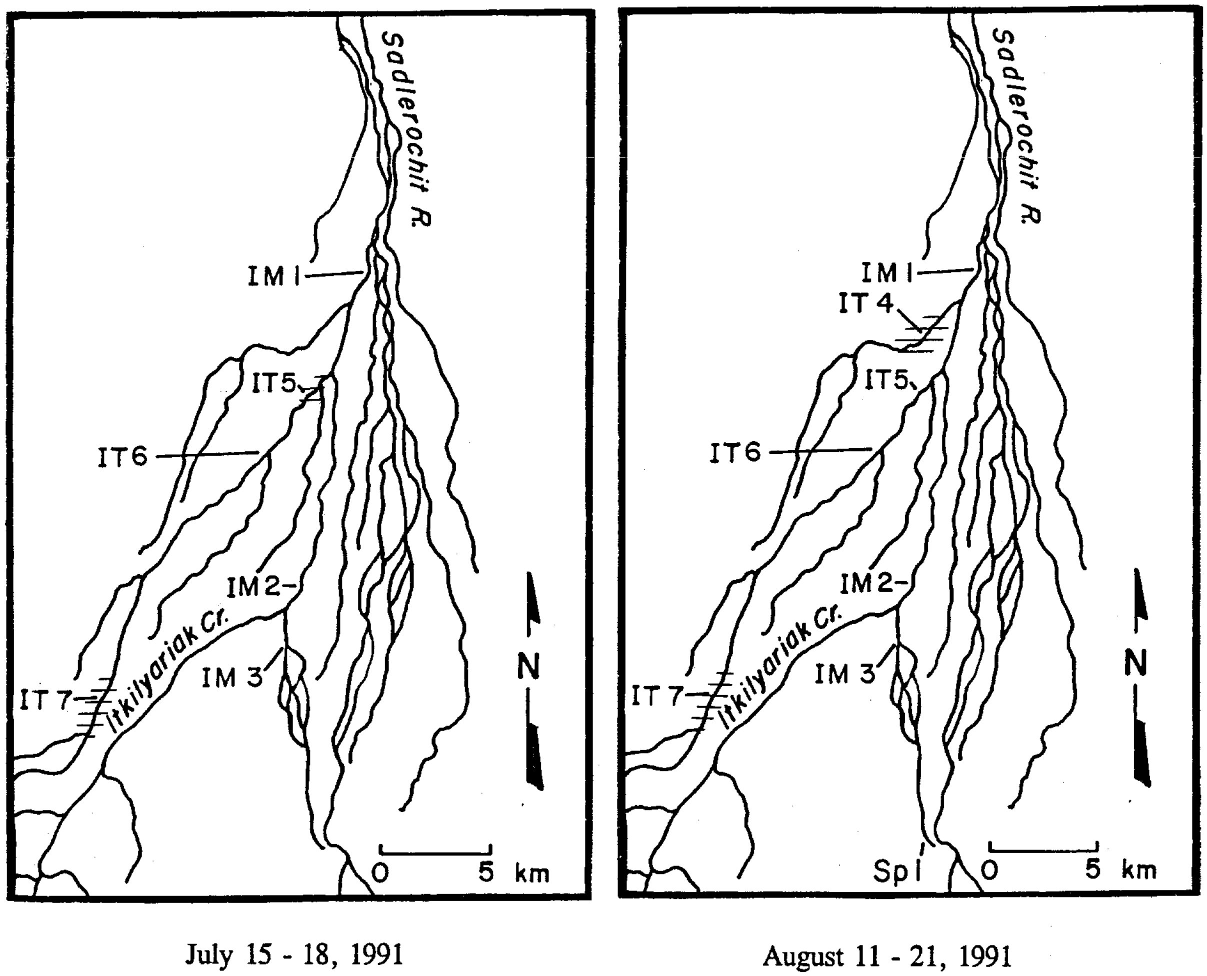


FIGURE 13.—Distribution of juvenile Arctic grayling (hatch marked) in Itkilyariak Creek during July and August 1991. IM = mainstem sampling site, IT = tributary site, Sp = Sadlerochit Spring site.

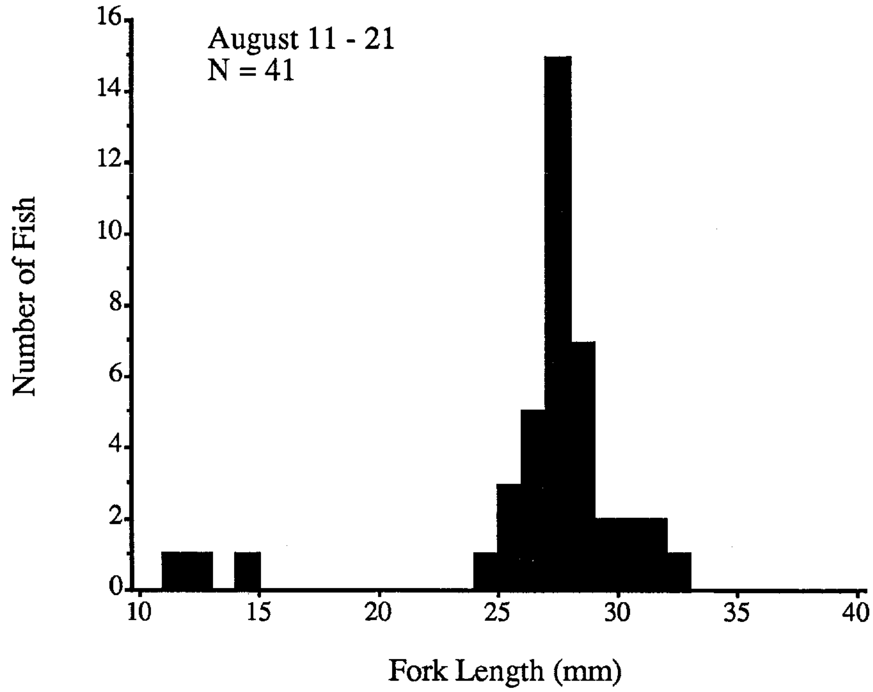


FIGURE 14.—Length-frequency of young of the year Arctic grayling captured in Itkilyariak Creek during August 1991.

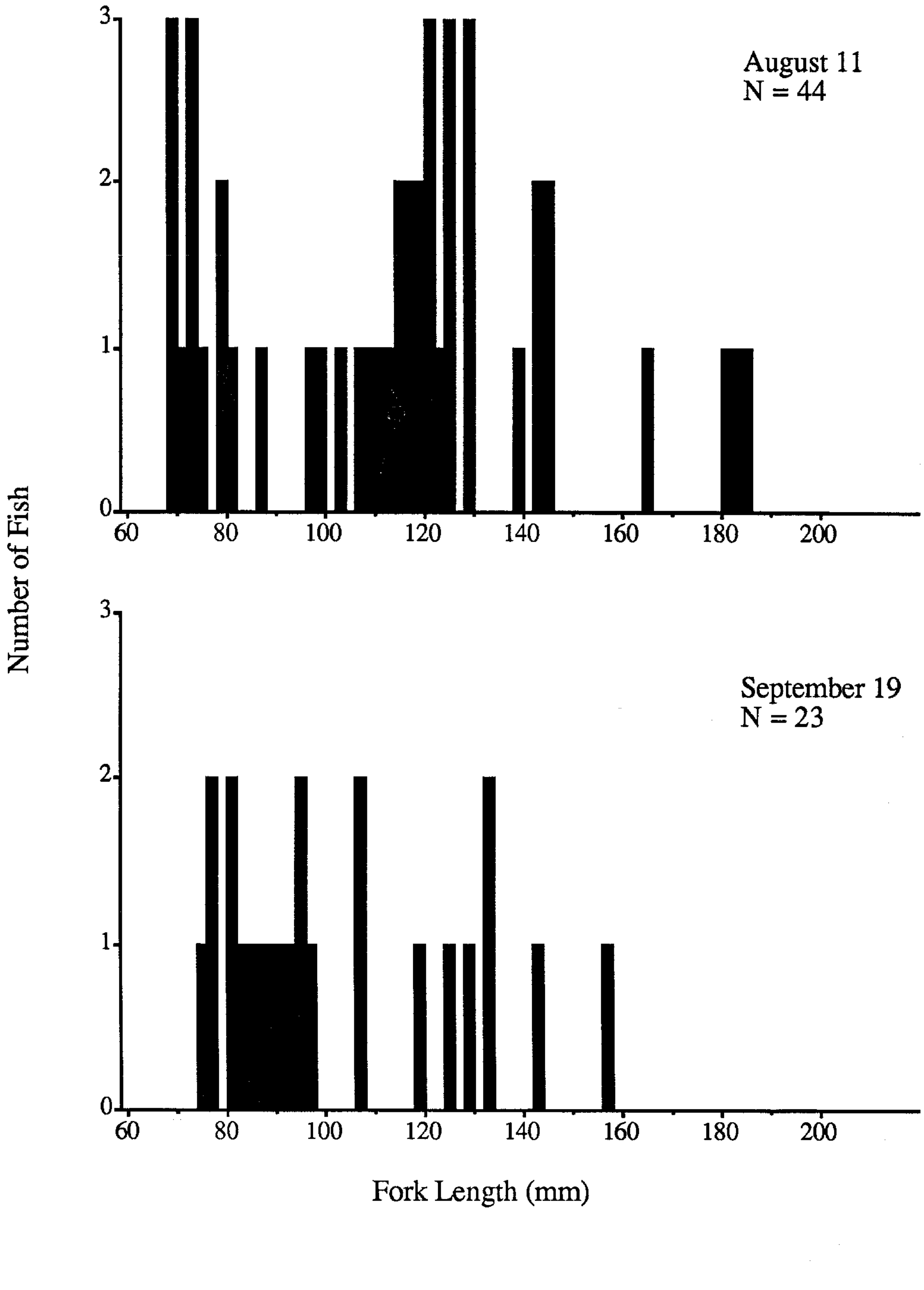


FIGURE 15.—Length-frequency of Dolly Varden char captured in Sadlerochit Spring during August and September 1991.

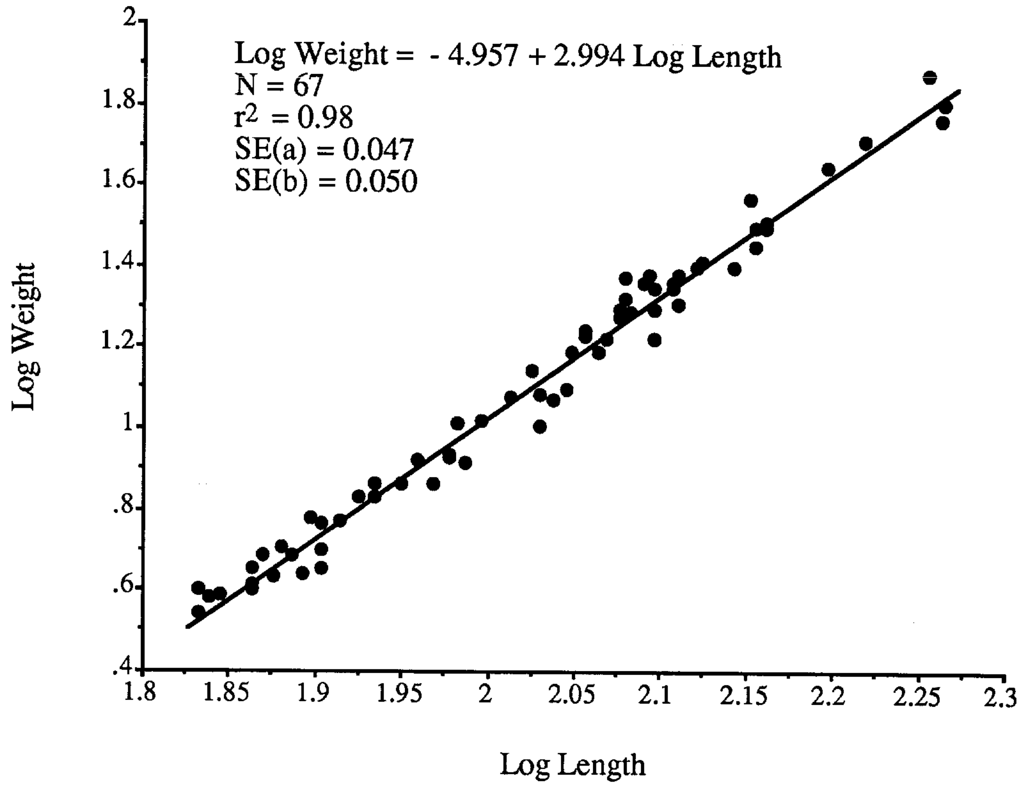


FIGURE 16.—Weight-length relationship of Dolly Varden char captured in Sadlerochit Spring during August and September 1991.

Conclusion

In 1991, the summer distribution of arctic fishes in the 1002 area of the Arctic Refuge was investigated in 19 lakes, 20 tundra streams and the Sadlerochit River drainage. Fish life history and distribution information was added to the baseline of previously sampled lakes and streams. In addition, this study documented the presence of fish in seven lakes, four tundra streams draining into coastal waters, and two tundra streams in the Sadlerochit River drainage where, prior to 1991, there were no data.

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Archives of Environmental Contamination and Toxicology

Drilling Fluids and the Arctic Tundra of Alaska: Assessing Contamination of Wetlands Habitat and the Toxicity to Aquatic Invertebrates and Fish

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Abstract. Drilling for oil on the North Slope of Alaska results in the release of large volumes of used drilling fluids into arctic wetlands. These releases, usually come from regulated discharges or seepage from reserve pits constructed to hold used drilling fluids. A study of five drill sites and their reserve pits showed an increase in common and trace elements and organic hydrocarbons in ponds near-to and distant from reserve pits. Ions elevated in water were Ba, Cl, Cr, K, SO_4 and Zn. Concentrations of Cu, Cr, Fe, Pb, and Si in sediments were higher in near and distant ponds than in control ponds. The predominant organics in drill site waters and sediments consisted of aromatic and paraffinic hydrocarbons characteristic of petroleum or a refined product of petroleum. In 96-hr exposures in the field, toxicity to *Daphnia Middendorffiana* was observed in water from all reserve pits, and from two of five near ponds, but not from distant ponds. In laboratory tests with *Daphnia magna*, growth and reproduction were reduced in dilutions of 2.5% drilling fluid (2.5 drilling fluid: 97.5 dilution water) from one reserve pit, and 25% drilling fluid from a second. Growth and reproduction were not affected at these dilutions of fluid from the other three reserve pits. Additional regulations—such as an upper limit on aromatic hydrocarbon content and toxicity to sensitive organisms—are needed to improve safety for aquatic organisms in habitats receiving used drilling fluids.

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The North Slope of the Brooks Range in Alaska is composed of moist and wet tundra and is the site of some of the most productive oil fields in North America. Prudhoe Bay is the center of this activity, and the origin of the trans Alaskan pipeline. During exploration and production, reserve pits are used for storage of excess drilling fluids, cuttings, boiler blowdown, and rig-washing fluids. More than 600 additives are potentially available for use in drilling fluids (API 1969; Dames and Moore 1978; National Research Council 1983). Many additives are known to be toxic, such as aromatic hydrocarbons, bactericides, brines, lignosulfonates, emulsifiers, and metals (ERL 1984). Despite the complex composition of reserve pit wastes and their potential toxicity to aquatic organisms and migratory birds, discharges from the pits occur more frequently on the North Slope of Alaska than at sites in the coterminous 48 States. Permafrost and low evaporation rates inhibit natural losses of reserve pit fluids, and repetitive use of the same reserve pit for multiple wells and fresh snowmelt each year continue to add volume to the pits. In a recent report, the Alaska Department of Environmental Conservation (ADEC) addressed the problems of disposal of reserve pit wastes (ADEC 1984). In 1984, ADEC permitted the discharge of reserve pit fluids into tundra wetlands from 23 pits in the Prudhoe Bay area, and in 1985 the fluids from about 40 reserve pits were discharged into the tundra in the Prudhoe Bay-Kuparik area, from both onshore and offshore sources.

In addition to oil production, the wetlands on the North slope serve as important summer nesting and rearing grounds for numerous species of shorebirds, waterfowl, seabirds, raptors, and passerines (Norton *et al.* 1975). Some of these species have no other known breeding ground or are threatened with extinction. Wetland ponds are rich in zooplankton, important in waterfowl food chains. The spring thaw in the wetlands and the production of invertebrates is closely tied to the time of waterfowl nesting, and coincides with peak discharges of drilling fluid wastes from reserve pits. Wetland ponds are connected by networks of natural troughs that eventually reach fish producing streams.

In 1983, the dewatering of reserve pits resulted in a significant impairment of water quality in ponds adjacent to reserve pits (West and Snyder-Conn 1987). When compared to ponds further from drill sites, adjacent ponds were lower in abundance and diversity of aquatic invertebrates. The present study was undertaken to better define the relationship between reserve pit fluids and toxicity to invertebrates and fish.

Drilling fluids are a complex waste effluent of inorganic and organic materials interacting together. More information is needed to correlate chemical characteristics of these effluents with their potential for causing adverse biological effects. The objectives of this study were to select five drilling sites in the Prudhoe Bay area, determine the inorganic and organic chemistry of water in the reserve pits and surrounding ponds, and correlate these findings with acute and chronic toxicity evaluations of water from these pits and ponds.

Methods

General

Five drilling sites and three control sites in the Prudhoe Bay area were selected for study in June 1985 in collaboration with ADEC and Atlantic Richfield Company, Alaska. Five Atlantic Richfield drilling sites were selected for our study, and a general history of the specific reserve pits evaluated is given in Table 1. In addition, we selected three control pond sites (CP1, CP2, CP3) to determine background concentrations of inorganic and organic constituents in area waters (Figure 1). At four drilling sites (4, 5, 6, and 7) three stations were sampled: the reserve pit (RP), a near pond (NP) within 50 m of the reserve pit, and a distant pond (DP) 100-200 m from the reserve pit (Figure 2). At site 8 only one RP and NP station were sampled. Thus, 17 stations—14 at drill sites and 3 at control sites—were sampled.

Field Sampling and General Chemistry

At each station, samples were taken for general water chemistry, and for the analysis of inorganics and organics in water and sediment (Figure 2). Samples for general water chemistry were collected at one location. Samples for inorganics in water were collected at three locations at NP and DP stations and one location at CP and RP stations. Samples for organics in water and sediments were collected at three locations at all stations. General water chemistry and sediment samples consisted of 1-L and 500-g grab samples, respectively. Water samples for the analysis of inorganics consisted of two subsamples—one filtered (0.45 μm) and acidified (ultra pure HCl to pH < 2), and one filtered and unacidified. Water samples for analysis of organics consisted of two subsamples—one 1-L grab and one extract taken by pumping 12 to 18 L of water through a glasswool prefilter and then through a pair of J. T. Baker C_{18} extraction columns followed by elution with hexane. Individual samples were analyzed and means were compared by analysis of variance and the least significant difference method for multiple means comparison (Snedecor and Cochran 1980). A 5% level was used to determine significant differences between CPs and the other pits and ponds.

At each of the five drill sites, 19-L of water were collected from RPs for acute and chronic toxicity testing in the laboratory. All water, sediment, and column extract samples were held at 4°C except during shipment (less than 24 hr) when maximum temperature reached 12°C. Column extracts, water, and sediment samples were shipped to Battelle Pacific Northwest Laboratories for chemical analyses. Sediment samples were frozen immediately on receipt. Water samples for toxicity testing were shipped to the U.S. Fish and Wildlife Service Research Station, Jackson, Wyoming.

General water quality characteristics were measured by standard methods (APHA 1980): temperature, calibrated thermometer; pH, standardized pH meter; dissolved oxygen, azide modification of the Winkler procedure; and conductivity, calibrated conductivity meter. Alkalinity and hardness were determined by titration. Total dissolved solids (TDS) were determined gravimetrically from the filterable residue with a 0.45 μm filter. The non-filterable residue was reported as suspended solids.

Water Analysis

Filtered inorganic water samples, both acidified and unacidified, were further filtered through a 0.22-μm filter before analysis. Unacidified samples were analyzed with a Dionex® Model 16 ion chromatograph to measure Cl, F, and SO_4. Fluoride was spot-checked with an ion selective electrode to ensure the validity of the ion chromatograph determinations. Organic carbon was determined with a Dohrmann® DC-80 carbon analyzer. Acidified samples were subjected to total elemental analysis in a Jarrell® Ash Model 975 inductive coupled plasma emission spectrometer.

Hexane extracts of columns were prepared for analysis of aromatic and paraffin hydrocarbons by concentrating the extracts to 4 mL under a stream of dry nitrogen and transferring the concentrate to Solu-Vials®. Samples were stored at −20°C until subjected to gas chromatographic (GC) analysis.

Sediment Analysis

For inorganic analysis, frozen samples were thawed and transferred to beakers and dried in an oven at 70°C. The dried samples were ground in a nico mill; they were then quartered and subsamples were further ground in a mortar to pass a 100 mesh screen. A subsample (0.1 g) of each sediment was placed in a 20 ml Teflon® insert of a Parr Digestion Bomb and 2.5 mL of

Table 1. Characteristics of drill site and specific reserve pits selected for study

Drill site	Reserve pit no[a]	Discharge date (June 1985)	Volume discharged bbls[b]	Date of last use	Location receiving discharge
4	7–2	24	176,000	1983	near pond
5	1–3	10	65,000	1981	near pond
6	16–2	~~10~~	100,000	1981	near pond
7	14–6	10	100,000	1984	near pond
8	12	no discharge		1984	seepage to near pond

[a] Drilling sites of Atlantic Richfield Company
[b] bbls = barrels or 159 L

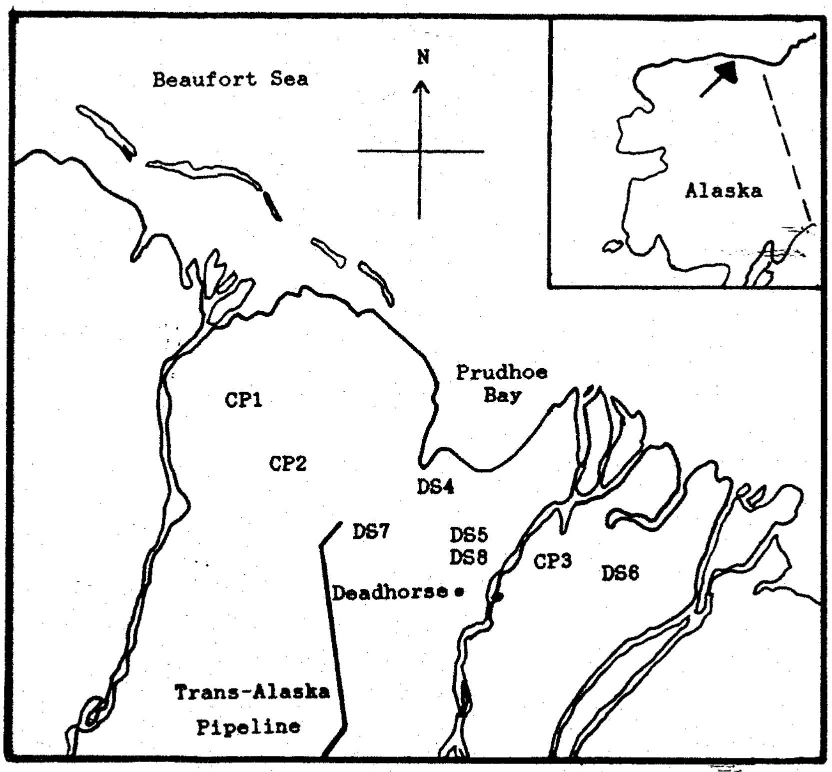

Fig. 1. Prudhoe Bay, Alaska, showing general location of drill sites (DS) and control ponds (CP) studied

concentrated ultra-pure nitric acid was added. Samples were sealed into a Parr Bomb and heated at 100–105°C for 20 hr. After digestion, samples were cooled and rinsed from the Teflon insert with deionized water and brought to a final volume of 20 mL. Each sample was mixed and allowed to stand overnight before analysis for inorganic ions by a Jarrell® Ash Model 975 inductive coupled plasma emission spectrometer.

Extracts of sediments were prepared for organic analysis by a modified of the procedure of Clark and Finley (1973). Individual sediment samples were thawed; and a 100-g subsample was placed into a 200 mL glass centrifuge bottle, stirred with 50 mL methonal, and centrifuged at 163 × *g* for 10 min. The methanol extraction was repeated once; supernatants were combined and poured through glass wool to remove mineral residue. The glass wool was rinsed with an additional 10 mL of methanol, which was combined with the methanol filtrate. To insure that organic constituents stayed in solution, we added 2 mL of benzene to the filtrate. The solution (sediment rinse) was set aside to be later combined with the Soxhlet extract of the sediment.

The methanol extracted sediment was transferred to a weighed Soxhlet thimble and extracted in a Soxhlet apparatus for 48 hr with a mixture of 180 mL benzene and 120 mL methanol. The Soxhlet thimble was dried and weighed to determine sediment dry weight. The extract was poured through glass wool to remove mineral residue and the wool and rinsed with 10 ml benzene. The extract and sediment rinse were combined and evaporated in a rotary evaporator to 20 mL. To insure removal of methanol, we added 4 mL of *n*-heptane and continued evaporation to 4 mL. The 4-mL concentrate was transferred to a 250 mL separatory funnel with 50 mL hexane and 10 mL saturated aqueous NaCl. Hexane extraction was preformed twice by shaking the separatory funnel for 1 min, and extracts were combined and dried over anhydrous Na_2SO_4. Dry hexane extracts were reduced to 6 mL by roto-evaporation, transferred to Solu-

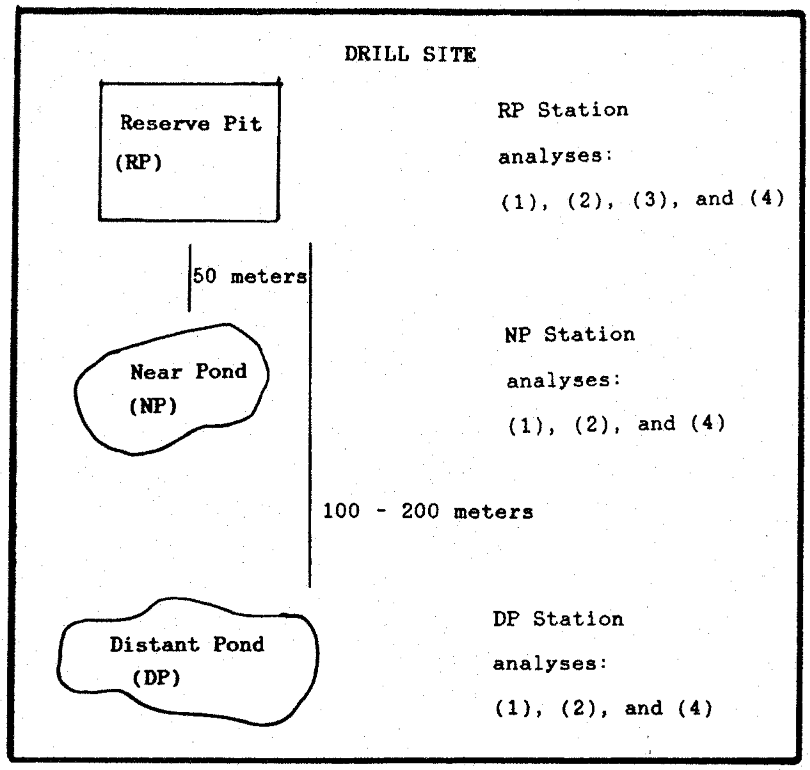

Fig. 2. Diagram of typical drill site, showing sampling stations. Type of analyses performed were (1) general chemistry, (2) water and sediments for specific organics and inorganics, (3) toxicity studies in the laboratory with Arctic grayling and *Daphnia magna*, and (4) toxicity studies in the field with *Daphnia middendorffiana*

Vials®, and further reduced to 4 mL by a stream of dry nitrogen. Metallic mercury was used to remove sulfur, by the procedure of Caragay *et al.* (1979).

Capillary GC and GC/Mass Spectrometry Analysis

Selected extracts of resin columns and sediment were amended with 50 μL of hexamethylbenzene internal standard and qualitatively screened for the presence of aromatic hydrocarbons on a Hewlett Packard 5880A GC coupled to a 5970A Mass Selective Detector. Data were accumulated on a Hewlett Packard 9133 Data System. The GC contained an 8M DB5 glass capillary column (J&W Sceintific Co.). Initial temperature was 50°C and programmed at a rate of 4°/min to 300°. Mass ions were scanned from m/e 40 to 400. Mass spectra acquired from the environmental samples were compared to those in the National Institute of Health data base to confirm structure (Heller and Milne 1978).

Individual hydrocarbon constituents in solvent extracts of resin columns, sediment, and tissue were quantified on a Hewlett Packard 5840 GC equipped with a flame ionization detector and a 15 m DB-5 capillary column (J & W Scientific). Samples were injected into the column at an oven temperature of 70°C. Following a four min hold, the oven temperature was programmed at 4°/min to a final temperature of 280°C; and after 20 min at this temperature, the sample was recycled to 70°C. Selected hydrocarbons (paraffinic straight chain from C_{10} to C_{29}, alkyl benzenes, mono-, di-, and tri-alkyl naphthalenes, biphenyl, fluorene, and phenanthrene) in the samples were identified by retention time and quantified, using mixtures of paraffinic and aromatic standards employing an internal standard method. For purposes of consolidating and reporting, individual paraffinic and aromatic hydrocarbons were summed and reported as total aromatic and paraffinic hydrocarbon concentrations. The detection limit for individual hydrocarbons in the different sample components was as follows: sediment samples (about 100 g dry weight), 10 ng/g; resin extracted water (about 20 L), 2 ng/L; and tissue (about 2 g), 100 ng/g.

Toxicity Studies

In the laboratory, we performed acute toxicity tests for 96 hr with Arctic grayling (*Thymallus arcticus*) and 48 hr with the zooplankter *Daphnia magna*, using RP fluid from sites 4, 5, 6, 7, and 8. Chronic tests were also conducted with daphnids for 42 days by the static renewal procedure. Grayling were obtained from the Flathead Lake Salmon Hatchery (Montana) as eyed eggs and tested as 1-1.5 g fry according to standard procedures (APHA 1980). *Daphnia magna* were reared and tested in the laboratory according to procedures described by Buikema *et al.* (1980). Photoperiod was controlled at 24 hr light, and temperature was 12 ± 2°C. Maximum concentration used in the acute exposures was 100% RP fluid; the end point was death. Exposure dilutions in the chronic tests were 25, 2.5, 0.25, and 0% RP fluid (25% = 25 parts RP fluid; 75 parts dilution water). The end point was effect on reproduction and growth. We used 10 organisms for each dilution and determined time to first brood, number of young per reproductive day, and length at 42 days for each organism. Means were compared between the 0% RP fluid and the other test dilutions for each variable by analysis of variance and the least significant difference test for multiple means comparison (Snedecor and Cochran 1980). A 5% level of significance was used.

Samples of water and fish were collected for analysis from the highest concentration that did not cause mortality and the control in each of the five acute tests. At the end of the 96-hr exposure, we pumped 5 L of the test water through extraction columns and froze five fish; the extracts and frozen fish were shipped to Battelle Pacific Northwest Laboratories for inorganic and organic analysis.

Experiments were performed in the field to evaluate whole-effluent toxicity to local populations of *Daphnia middendorffiana* under natural conditions of temperature, light, and water quality. These tests were performed some 1-3 weeks after the sampling. Daphnids collected from clean ponds were transferred into 150-mL cups, ends of which had been replaced with 125-mM polypropylene screen that allowed a flow of water. Eight cups containing 20 daphnids each were placed in each RP, NP, and DP at drill sites 4 to 8. We also placed eight cups into each of five clean reference ponds. (However, these ponds were different from the CPs chosen for determining background chemical concentrations). At 24, 48, 72, and 96 hr, two cups were removed from each site and examined under a dissecting scope to determine immobility or death. Due to counting errors and escapes, the number of dead and living organisms did not always total 20 per cup. Percent mortality was therefore based on those organisms present on the day of final counting. The Friedman Rank Analysis of Variance was used for comparison of all sites, and the Wilcoxon Rank Sum Test for comparisons between RP, NP, DP, and CP at a site (Snedecor and Cochran 1980).

Tissue Analyses

Fish samples from the Jackson laboratory were thawed and chopped with a stainless steel knife. Duplicate 0.1-g subsamples were taken for analysis of inorganics and a single 2-g sample was taken for organic analysis. Samples for inorganic analyses were freeze-dried, ground with a 100 mesh agate mortar, put into a Teflon insert with 2.5 mL of concentrated pure nitric acid, and sealed into a Parr digestion bomb. The bomb was held in an oven at 100°C for 18 hr. After digestion, the samples were cooled to room temperature, rinsed from the Teflon insert with deionized water, and brought to a final volume of 20 mL. Samples were analyzed by a Jarrell[R] Ash Model 975 inductive coupled plasma emission spectrometer.

Samples for analysis of organics were tared into 15 mL glass tissue grinders and homogenized three times with 5 mL portions of methanol, followed by one homogenization with 5 mL of hexane. The combined extracts were placed in a 25-mL Corex[R] centrifuge tube and vigorously shaken. Each sample was centrifuged at 163 × *g* for 5 min. The hexane layer was transferred to Solu-Vials[R] and the process was repeated a second time with an additional 5 ml of hexane. Hexane extracts were combined, concentrated to 1 mL under a stream of dry nitrogen, and refrigerated until analysis by GC.

Results

Residue Analysis

The concentrations of total dissolved ions and dissolved organic carbons were elevated at several of the RP, NP, and DP stations (Table 2). At RP4 and RP7 values were about 10-fold higher than at CP stations for measurements of conductivity and dissolved organics. Alkalinity and pH showed no apparent trends between stations.

Maximum concentrations of individual ions measured in RP waters exceeded those at CP sites by the following magnitudes: SO_4, 920 times; Br, 555 times; B, 230 times; Mn, 68 times; and Cl, Fe, K, and Na, 20 to 34 times (Table 3). Concentrations of ions were most frequently highest at RP7. Concentration of ions in sediment were also higher at RP7—concentrations of Pb, Cu, and Zn were greater than those at CPs by factors of 216, 105, and 21, respectively. Other ions found in the sediment at concentrations 20 to 30 times greater than in CPs were Ba at all sites, Cr at RP8, and Pb at RP6.

Ions elevated in RP water were also significantly increased in NP and DP water (Table 4); only those significantly increased above CP waters are reported here. Concentrations of Cl, K, and SO_4 were significantly elevated in eight of the nine NPs or DPs sampled, and Ba and Na were significantly elevated at seven. The magnitude of increase was greatest for SO_4: in NP and DP water, it was elevated by 80- to 470-fold above the mean of the CP stations. Trace elements Cr and Zn at NP4 and 7 were increased 3- to 6-fold above background concentrations.

Ions in NP and DP sediments that were significantly higher than the CP sample means are shown in Table 5. Barium concentrations were also high at some NP and DP stations, but not significantly above those for CPs because variation was large. For the seven NP and DP stations where triplicate samples were analyzed, Cu, Cr, Fe, Pb, and Si were the most frequently elevated. Increases over background were greatest at NP6, where concentrations of Pb and Cr were increased by 22- and 14-fold, respectively.

Four water samples (RP5, 6, and 8; DP7) and three sediment samples (RP5, 7, and 8) were selected for more detailed qualitative evaluation by GC/mass spectrometry (Table 6). The criteria for selection involved identifying samples with the greatest chemical complexity based on initial GC screening. Information obtained from this screening study was used to confirm the presence of aromatic (petroleum) hydrocarbons in selected samples and to determine which hydrocarbons were to be quantified by GC employing a flame ionization detector and analytical standards. Most common detectable constituents were the mono-, di-, and tri-alkylated naphthalenes. Water sampled from DP7 and sediments from RP5 and 7 contained the greatest number of detectable aromatic components.

Table 2. General water quality characteristics at sites 1–8 for different stations: control pond (CP), distant pond (DP), near pond (NP), and reserve pit (RP); nm = not measured

Sampling sites and stations	Conductivity (μS/cm)	TDS[a] (mg/L)	Suspended solids (mg/L)	pH	Alkalinity (mg/L)	Dissolved organic C (mg/L)
CP1	287	nm	nm	8.5	97	5.3
CP2	320	nm	nm	8.2	320	13.6
CP3	537	266	nm	8.3	127	11.9
Mean	381	nm	nm	8.3	181	10.3
DP4	1,240	657	10	8.5	133	20.0
NP4	1,655	1,176	43	8.3	178	45.9
RP4	4,200	2,081	243	8.3	271	102.0
DP5	907	556	0	8.2	163	16.4
NP5	1,498	757	1	8.0	218	18.7
RP5	3,283	1,555	186	8.4	332	55.2
DP6	388	173	0	8.4	115	7.9
NP6	1,490	595	16	8.2	328	15.5
RP6	1,917	604	14	8.6	349	16.1
DP7	2,533	931	17	8.3	285	28.1
NP7	2,933	1,477	82	8.3	342	69.7
RP7	4,100	2,285	314	8.4	335	95.3
NP8	700	579	8	8.7	176	17.7
RP8	3,200	1,666	500	8.3	137	75.5

[a] Total dissolved solids

Summation of individual aromatic and paraffinic hydrocarbons measured in water and sediment revealed an enrichment at some stations (Table 7). Concentrations of aromatic hydrocarbons in water were significanty increased above the highest CP value at RP5 and 8 and at DP7. Aromatics were not detected in the CP sediments but were found at 10 of the 14 stations at sites 4 to 8. Paraffinic hydrocarbons occur naturally in sediment, and are characterized by a predominance of odd-numbered components attributable to biogenic origins (Blumer *et al.* 1972). The presence of petroleum results in a more equal balance of odd- and even-numbered paraffinic hydrocarbons, and the ratio of n-C_{17} to pristane is often used to detect differences in clean and contaminanted sediments. The significance of these ratios has been discussed (Farrington *et al.* 1973), and shown to be about 1.5 to 1.8 for crude oil and increase in sediments containing weathered oil (Anderson *et al.* 1978). This ratio was greater than 25 for the CP stations. Of the 14 stations at sites 4 through 8, 12 showed ratios of n-C_{17} to pristane of 1.0 to 3.2. At seven of these stations paraffinic hydrocarbon concentrations were also two or more times greater than at the CPs. Qualitative examination of the chromatographic profiles of all samples suggests that the organic form of contamination consists of crude petroleum or a refined product of crude petroleum.

Toxicity Studies

In laboratory tests, no mortality or sublethal effects resulted from exposing either Arctic grayling for 96 hr or *Daphnia magna* for 48 hr to 100% drilling fluid from RP4 - 8. Tissue concentrations of specific organics or inorganics did not increase, except for Fe in fish (which was 2-fold higher in fish exposed to RP6 than in those unexposed). In field tests, significant mortality of *Daphnia middendorffiana* was induced at 96 hr by water from all RP stations and at NP5 and 6 (Table 8). Toxicity was much less apparent at 48 hr; mortality in water at NP4, 7, and 8, and at DP4 through 8 did not differ significantly from CP mortality at 96 hr.

Reduced reproduction and growth were observed after 42 days exposure of *Daphnia magna* to dilutions of drilling fluids from sites 5 and 8 (Table 9). The number of young produced and their mean lengths at 42 days were significantly reduced in organisms exposed to drilling fluid dilutions of 25% and 2.5% from site 8 and 25% from site 5. Time to first brood for those organisms developing in the

Table 3. Inorganic ions in water (mg/L) and sediment (mg/kg) of reserve pits at sites 4–8 as compared with mean for control ponds (standard deviations in parentheses). Values indicated by less than (<) for controls ponds are the detection limits; nm = not measured

Sampling stations and sites	Ions Al	B	Ba	Br	Cd	Cl	Co	Cr
	Water							
Control ponds (CP)	<0.10	<0.01	0.02 (0.01)	0.09 (0.07)	<0.006	39 (26)	<0.02	<0.04
Reserve pits								
RP4	0.57	0.28	0.14	0.96	0.006	758	0.02	0.41
RP5	0.10	0.12	0.18	21	0.006	473	0.02	0.12
RP6	0.04	0.68	0.07	0.81	0.006	200	0.02	0.04
RP7	0.24	2.3	0.13	50	0.006	829	0.02	0.48
RP8	0.85	0.11	0.10	1.2	0.006	470	0.02	0.49
	Sediment							
Control ponds (CP)	8,707 (1,467)	29 (12)	213 (58)	nm	2.0 (0.82)	nm	7.3 (0.58)	39 (13)
Reserve pits								
RP4	15,100	20	5,500	nm	3	nm	10	302
RP5	15,800	10	7,380	nm	3	nm	13	444
RP6	21,000	13	6,040	nm	6	nm	17	301
RP7	7,520	20	4,320	nm	4	nm	13	187
RP8	19,900	11	6,200	nm	3	nm	15	792

Sampling stations and sites	Ions Cu	F	Fe	K	Li	Mn	Mo	Na
	Water							
Control ponds (CP)	<0.006	0.13 (0.04)	0.06 (0.03)	<0.30	0.011 (0.004)	<0.002	<0.05	21 (17)
Reserve pits								
RP4	0.095	1.6	0.75	2.5	0.024	0.043	0.05	644
RP5	0.008	1.2	0.14	6.4	0.043	0.037	0.05	448
RP6	0.007	0.35	0.57	0.3	0.005	0.003	0.05	183
RP7	0.036	1.9	0.90	7.5	0.072	0.136	0.05	706
RP8	0.085	1.2	1.18	1.8	0.005	0.023	0.05	497
	Sediment							
Control ponds (CP)	17 (6.0)	nm	17,967 (2,173)	1,183 (425)	40 (18)	366 (206)	3.0 (1.2)	688 (215)
Reserve pits								
RP4	28	nm	19,600	3,100	45	296	5	4,560
RP5	44	nm	23,600	3,000	41	300	7	2,940
RP6	83	nm	35,400	3,700	52	512	8	4,560
RP7	1,780	nm	30,000	1,000	60	484	11	1,620
RP8	38	nm	31,000	3,700	49	464	4	5,400

Sampling stations and sites	Ions Ni	Pb	Sb	Si	Sr	SO^4	Ti	Zn
	Water							
Control ponds (CP)	<0.02	<0.06	<0.05	<0.30	0.11 (0.10)	0.34 (0.13)	<0.005	<0.02
Reserve pits								
RP4	0.02	0.06	0.05	2.79	0.19	313	0.045	0.04
RP5	0.02	0.06	0.05	4.51	0.32	144	0.023	0.02
RP6	0.02	0.06	0.05	1.03	0.10	38	0.005	0.02
RP7	0.02	0.06	0.05	4.06	0.42	204	0.067	0.02
RP8	0.02	0.06	0.05	3.43	0.14	245	0.051	0.10
	Sediment							
Control ponds (CP)	35 (4.1)	6.0 (7.1)	14 (13)	111,000 (40,037)	85 (48)	nm	12 (3.5)	109 (33)
Reserve pits								
RP4	38	15	39	nm	104	nm	3	72
RP5	38	36	40	nm	127	nm	0	112
RP6	73	150	53	nm	128	nm	14	280
RP7	78	1,300	43	nm	242	nm	37	2,290
RP8	71	15	51	nm	104	nm	6	204

Table 4. Mean concentration (mg/L) of inorganic ions found in water from ponds near and distant to drilling fluids reserve pits at sites 4–8, and control ponds. Standard deviations shown in parentheses. Values indicated by less than (<) for control ponds are the detection limits

Sampling stations and sites	Ions B	Ba	Br	Ca	Cl	Cr	F
Control ponds (CP)	<0.01	0.02	0.09	30	39	<0.04	0.13
		(0.01)	(0.07)	(7.6)	(26)	—	(0.04)
Distant ponds							
DP4	0.07	0.32[a]	1.1	65[a]	213[a]	0.05	0.15
	(0.03)	(0.02)		(9.2)	(48)	(0.01)	(0.04)
DP5	0.06	0.26[a]	5.2	59[a]	130[a]	0.04	0.16
	(0.002)	(0.02)		(9.4)	(5.7)		
DP6	0.04	0.09	0.10	35	32	0.04	0.09
	(0.01)	(0.01)		(4.0)	(1.5)		(0.01)
DP7	0.91[a]	0.35[a]	8.7	54[a]	206[a]	0.05	0.13
	(0.66)	(0.18)		(27)	(117)	(0.02)	(0.06)
Near ponds							
NP4	0.20	0.47[a]	0.91	64[a]	354[a]	0.11[a]	0.20[a]
	(0.04)	(0.05)		(0.71)	(16)	(0.01)	(0.01)
NP5	0.08	0.34[a]	9.7[a]	65[a]	207[a]	0.04	0.17
	(0.03)	(0.03)	(2.8)	(1.9)	(3.6)		(0.01)
NP6	0.65[a]	0.27[a]	0.97	27	178[a]	0.04	0.17
	(0.02)	(0.04)		(0.14)	(11)		(0.01)
NP7	2.3[a]	0.30[a]	40[a]	98[a]	426[a]	0.20[a]	0.22[a]
	(0.1)	(0.24)	(3.8)	(17)	(27)	(0.002)	(0.03)
NP8	0.16	0.17	1.6	30	180[a]	0.05	0.23[a]
	(0.04)	(0.02)		(0.71)	(45)	(0.01)	(0.01)

[a] Significantly greater than control pond or lowest distant pond value (least significant difference test, $P \leq 0.05$)

25% dilution was significantly increased for water from RP8, and reduced for water from RP6 and 7.

Discussion

Residue Analysis

The specific inorganic ions measured in the study that were elevated in the reserve pits and the surrounding environment of Prudhoe Bay have also been high in other areas where drilling has been concentrated. Murphy and Kehew (1984) found that leachate and groundwater from several drill sites in North Dakota exceeded recommended limits of several trace elements and major ions, such as As, Cd, Cl, Pb, Se, and SO_4. Other investigators have demonstrated high concentrations of Al, Ba, Cu, Cr, Fe, Mn, Na, Sr, and Zn in drilling fluids and their discharges (ERL 1984; Deeley and Canter 1986; Duke and Parrish 1984). Most of these ions can be traced to the additives used in drilling fluids (API 1969; Collins 1975; National Research Council 1983; Wright 1978). Saltwater, the most common base for drilling fluids, is the source of high Na and Cl concentrations. Barite ($BaSO_4$) and Pb compounds are used as weighting materials, and the Ba is frequently contaminated with Cd and Cu (Neff 1982). Materials used to control corrosion often contain compounds of Cu, Cr, and As. Chromium complexes are also used in drilling fluids as viscosity controllers; because of the solubility and toxicity of some of its forms, Cr in drilling fluids has received more attention than most other inorganic ions (Carr *et al.* 1982; West and Snyder-Conn 1987).

Comparisons of ion concentrations between studies are sometimes difficult because the analytical techniques differed. Methods include analysis of drilling fluid without any physical separation (total); analysis after particulate removal by centrifugation, filtering, or settling (dissolved); and analysis after equilibrium dialysis (free). The ion concentrations in our study could be defined as dissolved or soluble, based on separation by filtration. A review of water quality limitations on the basis of dissolved ion concentration indicates that Cr and Mn measured in Prudhoe Bay NP and DP waters in the study were above concentration considered acceptable for aquatic life (USEPA 1973, 1976). These trace metals at NP7 were 2 and 8 times greater than the 0.1 mg/L concentration regarded as safe for the protection of aquatic life. The significance of the Br and Sr concentrations is more difficult to assess. Bromine could cause toxicity at concentrations above 0.1 mg/L; however, in the salt form as

Table 4. (cont'd)

Fe	K	Mg	Mn	Na	Si	SO4	Sr	Zn
0.06	<0.30	4.3	<0.002	21	<0.30	0.34	0.11	<0.02
(0.03)		(1.5)		(17)		(0.13)	(0.10)	
0.10	3.3[a]	12[a]	0.013	157[a]	0.34	56[a]	0.27[a]	0.02
(0.03)	(0.5)	(1.1)	(0.004)	(56)	(0.18)	(36)	(0.01)	
0.05	4.2[a]	4.0	0.006	99[a]	1.1[a]	50[a]	0.25[a]	0.02
(0.01)	(0.1)	(0.7)	(0.001)	(62)	(0.2)	(3.6)	(0.01)	
0.06	0.61	2.9	0.004	12	0.30		0.10	0.02
(0.02)	(0.06)	(0.3)	(0.001)	(1.2)			(0.00)	
0.52[a]	1.6[a]	5.6	0.14[a]	6.4	0.64	56[a]	0.28[a]	0.04
(0.42)	(1.7)	(3.9)	(0.13)		(0.70)	(35)	(0.20)	(0.01)
0.37[a]	4.9[a]	9.7[a]	0.027	290[a]	1.3[a]	160[a]	0.26[a]	0.07[a]
(0.02)	(0.9)	(0.7)	(0.003)	(4.2)	(0.2)	(2.6)	(0.01)	(0.04)
0.17	5.2[a]	4.7	0.008	182[a]	1.1[a]	68[a]	0.31[a]	0.03
(0.02)	(0.1)	(0.4)	(0.003)	(10)	(0.2)	(9.5)	(0.03)	(0.01)
0.10	2.8[a]	3.7	0.012	166[a]	1.5[a]	42[a]	0.11	0.03
(0.01)	(0.1)	(0.0)	(0.002)	(2.8)	(0.2)	(3.8)	(0.00)	(0.02)
0.82[a]	8.3[a]	13[a]	0.84[a]	373[a]	2.3[a]	121[a]	0.45[a]	0.05[a]
(0.06)	(1.4)	(2.6)	(0.02)	(5.7)	(0.2)	(2.1)	(0.04)	(0.01)
1.1[a]	5.9[a]	6.4	0.08	181[a]	0.46	27[a]	0.15	0.02
(0.4)	(0.3)	(0.4)	(0.02)	(8.5)	(0.23)	(5.3)	(0.03)	(0.01)

bromate, concentrations of 100 mg/L or greater would be required to create a hazard for aquatic life. Concentrations of most ions measured in NP and DP exceeded 0.1 mg/L but we do not know how much Br was present as bromine or bromate; in our dissolved fractions, both forms would have been measured. Limited information is available on Sr, but it appeared to be above normal surface water concentrations at most NP and DP stations (Vanderploeg *et al.* 1975). The elevation of common ions, such as Ca, Cl, K, Mg, Na, and SO_4 in NPs and DPs would not cause a biologic impact at the concentrations measured, but would increase the total dissolved solids and conductivity, as was observed.

Safe limits are not established for ion concentrations in sediment, because the presence of an ion in sediment does not mean it is available or in a toxic form. However, the sediment ions elevated most frequently above background in our study—Cr and Pb—were within the range of sediment metal concentrations reported in an area of heavy industrial pollution by Malueg *et al.* (1984). Sediment concentrations at several lake sites near the treatment plant outfall of a metal-plating factory were 140–980 mg/kg for Cr and 59–160 mg/kg for Pb. In the present study, both Cr and Pb were within these ranges at site NP6, and Cr was within this range at sites NP7, NP4, DP7, and NP8. Sediment concentrations of Cu, though elevated above background in this study, did not approach the concentrations of 1,800 to 2,700 mg/kg measured in aquatic sediments below copper mines in Michigan and California (Malueg *et al.* 1984).

The concentration of aromatic hydrocarbons in water at CP sites was consistent with concentrations observed in open surface waters of the ocean, remote from sites of oil exploration and production (Clark and MacLeod 1977). At some RP and DP sites in our study, waters contained aromatic hydrocarbons indicative of historical crude or refined oil input. Concentrations of aromatic hydrocarbons at RP5 and 8 and DP7 were 9.3, 6.2, and 9.6 μg/L respectively, as compared with 9.2 μg/liter in a stream below the point of discharge from a Wyoming oilfield (Woodward and Riley 1983).

The hydrocarbon content of sediments in contaminated coastal areas ranges from 100 to 12,000 mg/kg and most concentrations are less than 1,000 mg/kg; in contrast, the concentrations in uncontaminated coastal areas and deep marginal seas or basins are usually below 70 mg/kg (National Research Council 1975; Clark and MacLeod 1977). Sediment from remote deep sea areas generally contain less than 2 mg/kg total hydrocarbons, most of which are of biogenic origin. Concentrations of

Table 5. Mean concentration (mg/kg) for inorganic ions found in sediment from ponds near and distant to drilling fluid reserve pits at sites 4–8. Standard deviations in parentheses; nm = not measured

Sampling stations and sites	Ions Ba	Ca	Cl	Cr	Cu	Fe
Control ponds	213	41,667	517	39	17	17,967
(CP)	(58)	(32,241)	(161)	(13)	(6.0)	(2,173)
Distant ponds						
DP4	436	16,200	nm	120	26	12,000
DP5	818	84,000[a]	650	57	18	24,933
	(216)	(54,442)	(71)	(7.6)	(2.6)	(3,800)
DP6	292	36,400	350	50	18	30,933[a]
	(99)	(6,002)	(71)	(6.9)	(3.2)	(6,804)
DP7	17,737	46,067	750	189[a]	39[a]	31,267[a]
	(17,228)	(17,997)	(354)	(118)	(11)	(12,582)
Near ponds						
NP4	1,560	80,800	nm	180	32	21,100
NP5	2,687	107,033[a]	300	107	24	26,900
	(315)	(30,939)	(00)	(58)	(1.5)	(1,709)
NP6	5,386	28,966	300	559[a]	45[a]	39,333[a]
	(2,311)	(802)	(141)	(82)	(2.1)	(7,390)
NP7	9,593	49,567	600	285[a]	42[a]	38,400[a]
	(11,878)	(13,048)	(141)	(70)	(3.1)	(8,321)
NP8	3,093	64,833	950[a]	349[a]	46[a]	49,467[a]
	(1,367)	(9,808)	(212)	(120)	(4.0)	(3,802)

[a] Significantly different from control ponds least significant difference test, $P \leq 0.05$)

total hydrocarbons (aromatic plus paraffinic) at several stations in our study exceeded 100 mg/kg and were consistent with concentrations observed in polluted coastal areas of the world. Total hydrocarbon concentrations ranged from 146 to 837 mg/kg for RP5, 7, and 8; NP6, 7, and 8; and DP7. The source of organic contamination appears to be crude petroleum and a refined product. At the other extreme, total hydrocarbon in sediment was below 56 mg/kg at all CP sites; these concentrations could be attributed to biogenic origin.

The specific aromatic hydrocarbons identified in the present study are similar to the components found in discharges from marine drilling operations by Hiatt and Jones (1985). Naphthalene and methylnaphthalene compounds were routinely detected in discharges from seven offshore sites in southern California using GC/mass spectrometry techniques. Diesel fuel and other petroleum products are common additives in drilling fluids (Neff 1982; National Research Council 1983), and low molecular weight aromatic components of petroleum originate from their use. Less detailed analyses by other investigators have also indicated the presence of fuel oil-like hydrocarbons in drilling fluids (Conklin *et al.* 1983; Duke and Parrish 1984). Diesel fuel, along with semivolatile aromatics like naphthalene, are restricted in offshore discharges of drilling fluids in California (Hiatt and Jones 1985). The concern over diesel fuel and light aromatic compounds is based on studies implicating their association with toxicity in drilling fluids (Conklin and Rao 1984; Duke and Parrish 1984; Tagatz *et al.* 1985).

Toxicity Studies

The greater daphnid mortality in the field tests as compared to laboratory tests, is not totally explainable. Laboratory exposures were conducted for 48 hr on only RP water. Although no mortality was observed in the laboratory, only the 48-hr data from RP stations in the field were strictly comparable with data from laboratory tests. Also, field tests were performed on *D. middendorffiana* and laboratory tests on *D. magna*; however, the results of tests with a number of different inorganic and organic chemicals have indicated that the sensitivities could be expected to be similar between species of *Daphnia* (Elnabarawy *et al.* 1986). The lack of conditioning to handling stress by the wild population, coupled with the exposures, may have resulted in greater sensitivity of *D. middendorffiana*.

Due to the high aromatic hydrocarbon concentration at DP7, one would expect mortality in the field exposure to be greater that 10%. However, field toxicity testing was performed 1–3 weeks

Table 5. (cont'd)

Mn	Mo	Pb	Si	Sr	Zn
366	3.0	6.0	111,000	85	109
(206)	(1.2)	(7.1)	(40,037)	(48)	(33)
382	nm	20	240	113	74
273	5.4	12	171,800[a]	133	100
(33)	(3.9)	(3.5)	(38,890)	(40)	(12)
350	2.7	9.3	138,500	64	83
(68)	(1.9)	(4.0)	(16,263)	(23)	(4.0)
880	5.2	44[a]	272,000[a]	129	102
(569)	(1.3)	(6.5)	(14,142)	(57)	(32)
552	6.0	30	508	140	94
1,205[a]	2.4	32[a]	224,000[a]	177[a]	96
(660)	(1.4)	(7.5)	(35,355)	(21)	(2.6)
840	8.4[a]	133[a]	214,000[a]	132	179[a]
(143)	(1.4)	(30)	(11,313)	(24)	(23)
1,351[a]	3.6	51[a]	240,000[a]	146	114
(300)	(3.4)	(5.2)	(18,385)	(35)	(12)
2,036[a]	11[a]	39[a]	242,000[a]	151[a]	173[a]
(120)	(2.2)	(5.0)	(15,556)	(26)	(16)

after sampling, and aromatic components might have been considerably diluted or lost during that time period.

The most sensitive biological effects were those measured on reproduction and growth of daphnids in dilutions of RP5 and RP8 test water. It is difficult to determine which characteristics of these waters contributed most to toxicity. However, the aromatic content was higher in both waters than in any of the other RPs, and the aromatics were represented by the low molecular weight compounds known to be the more toxic components of drilling fluids (Hiatt and Jones 1985; National Research Council 1983). As judged from mortality of individual aromatics to *D. pulex*, toxicity at 96 hr would be expected to occur between 100 and 1,000 μg/l for the type of hydrocarbons represented in RP5 and 8 (Trucco *et al.* 1983). Using the 0.01 application factor (EPA 1973), we estimated that the safe concentration for total aromatics was between 1 and 10 μg/L. Concentration of total aromatics at RP5 and 8 were within this range and possibly high enough to reduce growth and reproduction under the test dilutions.

The sensitivity of zooplankton was also demonstrated during experimental oil spills in freshwater ponds near Barrow, Alaska, by Barsdate *et al.* (1980). After a one-time crude oil introduction, daphnids and fairy shrimp were killed immediately and did not return for 7 years. They were the most sensitive of the zooplankters, and zooplankton was more sensitive than the other biological components measured—bacteria, benthic and planktonic algae, vascular plants, or aquatic insects. Laboratory experiments indicated that daphnids were killed when less than 0.2 ml/L oil was added. Vigorous aeration reduced mortality—indicating the

Table 6. Aromatic hydrocarbons identified by GC/mass spectrometry in selected sediment and water samples: reserve pits (RP) at sites 5, 6, 7, and 8; and distant pond (DP) at site 7. Concentration range given for water (μg/L) is L, 0.01–0.5; M, 0.5–1.0; and H, greater than 1.0. Concentration range for sediment (mg/kg) is L, 5–15; M, 15–25; and H, greater than 25. Individual constituent concentrations were determined by GC and calibrated analytical standards

	Water				Sediment		
Compound	RP5	RP6	RP8	DP7	RP5	RP7	RP8
Alkylated benzene				H			
Naphthalene				M	L		
Naphthalene							
monoalkylated	M	L	L	H	H	H	L
dialkylated	M	L	M	H	H	H	L
trialkylated	H		H	H	H	H	L
Fluorene				H	H		
Phenanthrene				H			

Table 7. Aromatic and paraffinic hydrocarbons found in water and sediment of control ponds (CP), distant ponds (DP), near ponds (NP), and reserve pits (RP). No standard deviation indicates only one sample analyzed

Sampling stations and sites	Aromatic				Paraffinic		
	Water conc. (μg/L)		Sediment conc. (mg/kg)		Sediment conc. (mg/kg)		Ratio nC17 to pristane
	mean	SD	mean	SD	mean	SD	
CP1	0.16	0.04	ND[a]		43	7.5	>25
CP2	0.08	0.04	ND		56	23	>26
CP3	0.07	0.01	ND		46	21	>35
DP4	0.22	0.12	ND		7		1.6
NP4	0.60	0.20	4.4		50		1.3
RP4	4.6	1.3	2.5		15		1.0
DP5	1.0	0.05	ND		59		>13
NP5	1.6	0.20	ND		33		3.2
RP5	9.3[b]	3.3	263		574		1.4
DP6	0.08	0.05	ND		68		>25
NP6	1.5	0.74	29		117		1.4
RP6	1.8	0.17	12		32		1.3
DP7	9.6[b]	12	59	45	316	128	1.3
NP7	3.3	0.28	18	12	245	157	1.5
RP7	1.2	0.37	180	283	516	733	1.2
NP8	0.56	0.33	130		700		1.3
RP8	6.2[b]	0.30	26		120		1.6

[a] ND = not detectable above limits of procedure, about 0.6 mg/L
[b] Significantly different from control station 1CP

Table 8. Mortality or immobility of *Daphnia middendorffiana* after exposure in the field at stations on drill sites 4–8

Drill site and station	Mortality or immobility (%)	
	48 hr	96 hr
Drill site 4		
Control pond	0	0
Distant pond	2	0
Near pond	0	0
Reserve pit	12	60[a]
Drill site 5		
Control pond	8	2
Distant pond	8	6
Near pond	5	72[a]
Reserve pit	74	100[a]
Drill site 6		
Control pond	3	2
Distant pond	5	0
Near pond	0	25[a]
Reserve pit	0	79[a]
Drill site 7		
Control pond	0	0
Distant pond	0	10
Near pond	8	14
Reserve pit	15	58[a]
Drill site 8		
Control pond	0	0
Near pond	8	10
Reserve pit	14	80[a]

[a] Significantly different from control pond ($P \leq 0.05$, Wilcoxon Rank Sum Test)

close relation between volatile aromatics and toxicity.

Some drilling fluids and their dilutions enhanced daphnid growth or production,—e.g., RP4 and 6 at 25% dilution. Water quality influences reproductive potential; and when toxic concentrations are not reached, the addition of inorganic materials sometimes improves reproductive success (Cowgill *et al.* 1986). Woodward *et al.* (1985) also found that daphnid reproduction increased where inorganics were elevated within the range of sublethal concentrations. Inorganics introduced during the exposure may enrich the test water, increase bacterial life and the food-base, and promote reproduction.

Our study was similar to a 1983 evaluation of the impacts of water quality on aquatic invertebrates in ponds adjacent to reserve pits in the Prudhoe Bay area (West and Snyder-Conn 1987). Ions elevated in receiving ponds and considered to be of greatest importance in the 1983 study were As, Ba, Cr, and Ni. Aliphatic and aromatic hydrocarbons were also elevated in receiving ponds. However, the concentrations are not comparable with those in our study because samples were unfiltered and values represented the total concentration rather than the dissolved fraction measured in our study. High turbidity, alkalinity, As, Ba, and Cr in the 1983 study were correlated with lowered taxonomic diversity and abundance of aquatic invertebrates. In our

Table 9. Effects of different dilutions of reserve pit fluids collected from sites 4–8 on reproduction and growth of *Daphnia magna* during 42 days of exposure

Drill site and testing dilution	Time to 1st Brood (days)		Young per reproductive day (no.)		Length (mm)	
	Mean	SD	Mean	SD	Mean	SD
Drill site 4						
0%	22	1.1	3.0	0.45	3.6	0.10
0.25%	22	0.5	2.8	0.37	3.7	0.05
2.5%	22	1.6	3.0	0.55	3.6	0.10
25%	22	1.6	3.6[a]	0.32	3.5	0.08
Drill site 5						
0%	22	1.1	3.1	0.45	3.5	0.10
0.25%	22	1.4	3.2	0.39	3.5	0.08
2.5%	22	2.2	3.5	0.29	3.6	0.08
25%	23	2.5	2.2[b]	0.63	3.2[b]	0.13
Drill site 6						
0%	23	1.3	3.4	0.74	3.6	0.10
0.25%	23	0.5	2.4	0.55	3.5	0.07
2.5%	23	2.5	3.0	0.40	3.7	0.04
25%	20[a]	1.0	3.2	0.43	3.9[a]	0.07
Drill site 7						
0%	25	1.3	2.3	1.00	3.5	0.15
0.25%	24	1.2	2.9	0.40	3.6	0.10
2.5%	24	1.9	3.0	0.90	3.6	0.10
25%	21[a]	0.5	3.2	0.61	3.7	0.15
Drill site 8						
0%	22	1.8	3.0	0.22	3.6	0.05
0.25%	24	1.4	3.3	0.16	3.7	0.08
2.5%	23	1.3	1.8[b]	0.30	3.4[b]	0.05
25%	30[b]	2.6	1.0[b]	0.39	2.7[b]	0.08

[a] Performance significantly above that of the controls (LSD; $P \leq 0.05$)
[b] Performance significantly below that of the controls (LSD; $P \leq 0.05$)

daphnid reproduction and growth study, RP5 and 8 had the greatest effect. In comparison with other RP stations, alkalinity and Ba were both high in RP5 and suspended solids (turbidity) and Cr were highest in RP8. We made no determinations for As.

It is obvious from the present study that drilling fluid discharges result in significant increases of both inorganic and organic constituents in the Alaska wetland environment. Some of these constituents were at concentrations above those considered acceptable for aquatic life, and some equalled concentrations found in polluted areas of the world. Although we observed toxic effects on zooplankton production for some RP dilutions, no adverse effects were observed where actual discharges were diluted below 25% (25 parts RP fluid: 75 parts dilution water). However, one RP where seepage was occurring, showed toxicity to daphnids at 2.5% fluid.

Along with the current criteria on drilling fluid discharge, additional limitations could increase the protection provided to the Alaskan environment. An upper limit on aromatic hydrocarbon content, such as the 10-μg/L concentration established for offshore discharge in California (Hiatt and Jones 1985) and proposed in Alaska (Larry Dietritz, personal communication), is supported by our study. Further protection could also be provided if daphnids were used as indicators of acute or subacute toxicity of drilling fluid waste waters. Toxicity, along with rate of discharge and volume of receiving waters, could be used to calculate a toxic emission factor (Nikunen and Miettinen 1985). This technique has been used for industrial discharges in Finland. Toxicity evaluations are particularly important for complex wastes such as drilling fluids because they alone enable one to assess the interaction of numerous inorganic and organic materials.

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