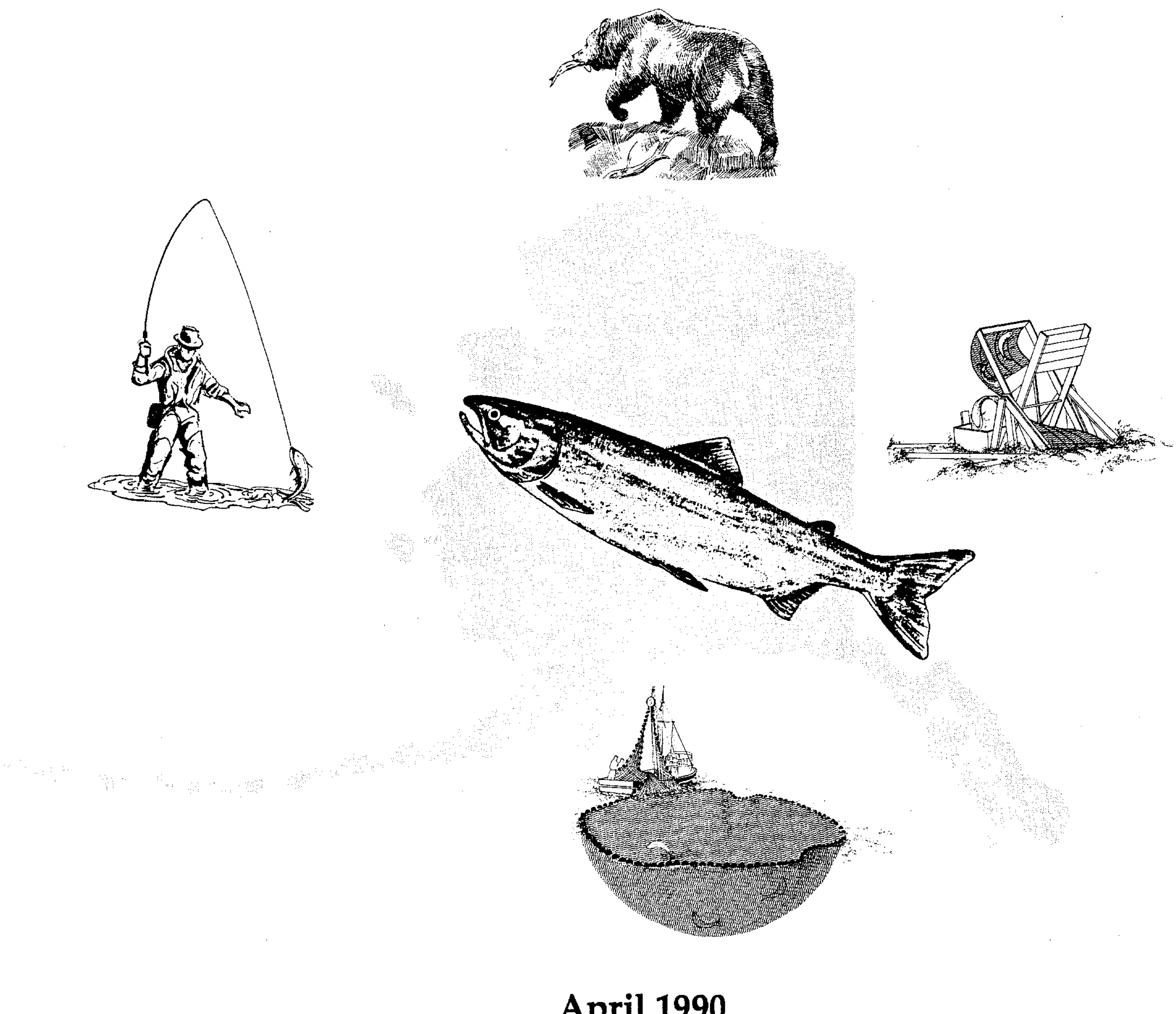
Alaska Fisheries Technical Report Number 6

QUANTIFICATION AND DISTRIBUTION OF WINTER WATER WITHIN RIVER SYSTEMS OF THE 1002 AREA, ARCTIC NATIONAL WILDLIFE REFUGE



April 1990

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

QUANTIFICATION AND DISTRIBUTION OF WINTER WATER WITHIN RIVER SYSTEMS OF THE 1002 AREA, ARCTIC NATIONAL WILDLIFE REFUGE

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Abstract

An inventory of the distribution and quantity of winter water in rivers was conducted within the 1002 area of the Arctic National Wildlife Refuge as part of an effort to develop a hydrologic data base, map sources of winter water, and determine water availability for oil and gas activities.

During April 10 through 19, 1989, locations of ice hummocks on all major river drainages in the area were identified using a LORAN navigation instrument. A subsample of nine hummocks was drilled to delineate water pool volumes. A positive linear relationship between hummock size and pool volume was developed and used to estimate the total volume of water available beneath all hummocks inventoried.

Although winter water was found to occur over a widespread area in most of the major river drainages in the 1002 area, the quantities were not great. Nearly 9 million gallons of water were estimated to be available along the 237 miles of river channel inventoried. It takes approximately 1,350,000 gal of water to construct and maintain each mile of ice road used to support oil exploration activities and 30,000 gal of water per day to support an oil exploration drill.

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Introduction

The location and quantity of water available in the frozen river systems during the winter months in the 1002 area of the Arctic National Wildlife Refuge (Figure 1) was studied to determine potential sources of water for oil exploration and development activities, such as ice roads, drill pads, and runways. Proposed oil and gas exploration and development may require significant quantities of water for these activities. Information on the spatial and temporal distribution of potential water sources is required to make informed decisions concerning the management of potential development so as to best protect aquatic habitats and the fish and wildlife resources that use them.

Water availability in the winter is strongly influenced by the climate which is characterized by extremely low winter temperatures and short, cool summers. Total annual precipitation averages 6.2 inches on Barter Island (Arctic Environmental Information and Data Center 1986). Ninety-nine percent of the 1002 area is classified as wetlands; however, water is limited and confined to the shallow zone above permafrost (Clough et al. 1987).

The major river drainages transecting the 1002 area are defined as mountain streams by Craig and McCart (1975). Perennial springs provide the only source of winter flow for mountain streams. Arcone et al. (1989) reported that ice cover along rivers throughout the 1002 area during winter months was generally frozen to the river beds, except for open reaches within aufeis areas that develop downstream from warm springs and beneath ice mounds found along the river channels (Figure 2). There is mention of ice structures similar to ice mounds in Alekseyev (1969) that are variously termed ice hummocks, naled hummocks, and heaving hummocks. Hummocks were reported in association with naleds or aufeisen (icings formed by extrusion of river or spring water), along stream courses, and beneath peat or vegetated soil cover (Alekseyev 1969, Are 1969, Bogomolov and Sklyarevskaya 1969, Bondarev and Gorbunov 1969, Bukayev 1969, Nekrasov 1969). The hummocks were reported forming over pressurized pools of water and in one case the pool beneath an ice hummock was determined to be hydraulically isolated (Are 1969). Nekrasov (1969) described several hummocks that were frozen to the substrate by late March and contained layers of substrate material within the ice.

Data gaps identified by Elliott (1989) provided the basis for investigations to determine availability of winter water in the 1002 area. The objectives of this study are to quantify the water volumes of pools beneath ice hummocks of frozen streams and rivers and the distribution of hummocks within the major 1002 drainages.

Methods

An inventory of ice hummocks within the rivers of the 1002 area was conducted April 10-19, 1989, at the approximate time of maximum ice development. A subsample of nine hummocks was measured for length, height, and water depth. Total length of each axis (length and width axis) was measured to the nearest foot using a fiberglass measuring tape. Maximum

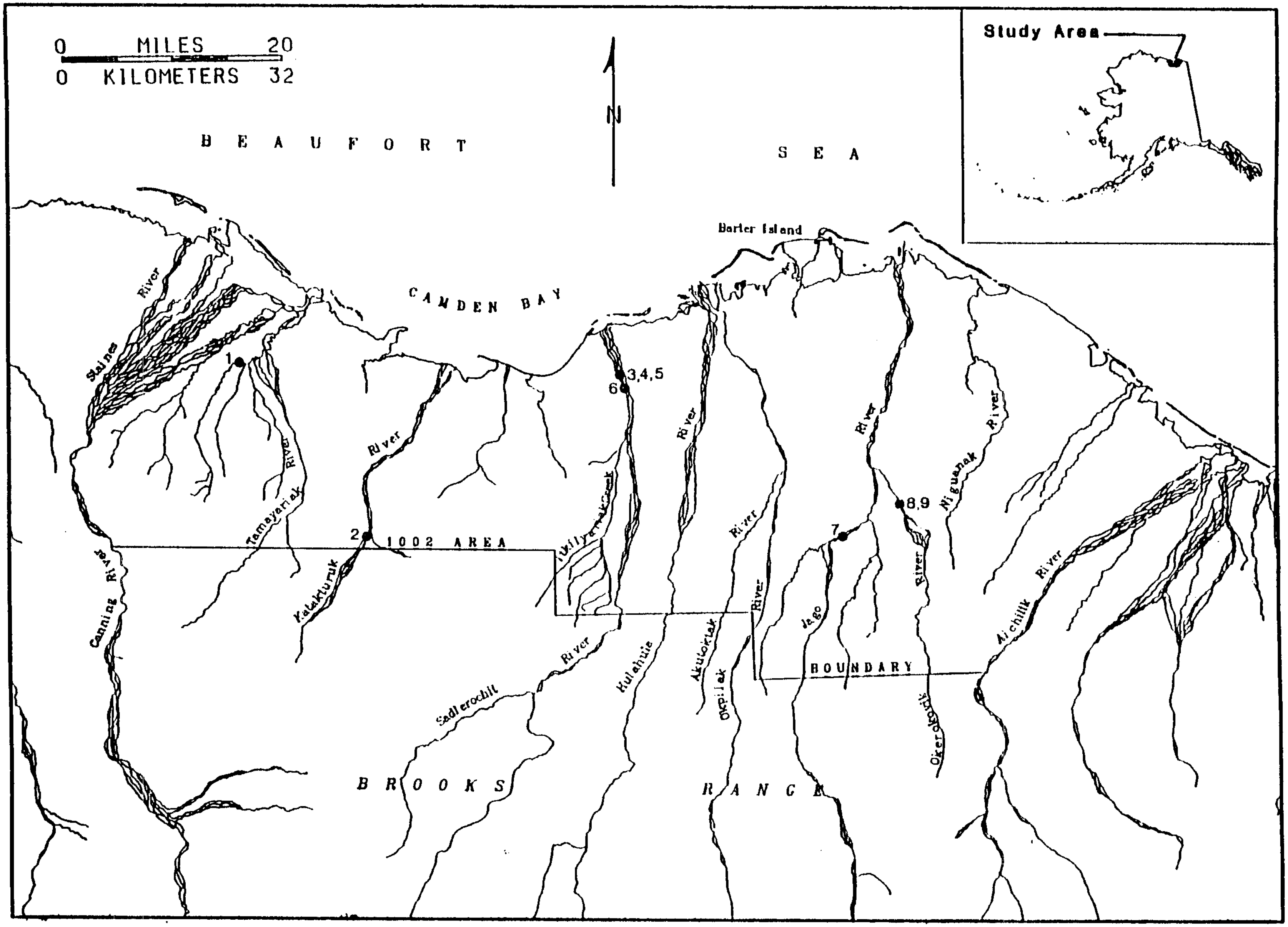

FIGURE 1.--The 1002 area, Arctic National Wildlife Refuge, Alaska, with locations of selected ice hummocks which were drilled for water and pool volume measurements.

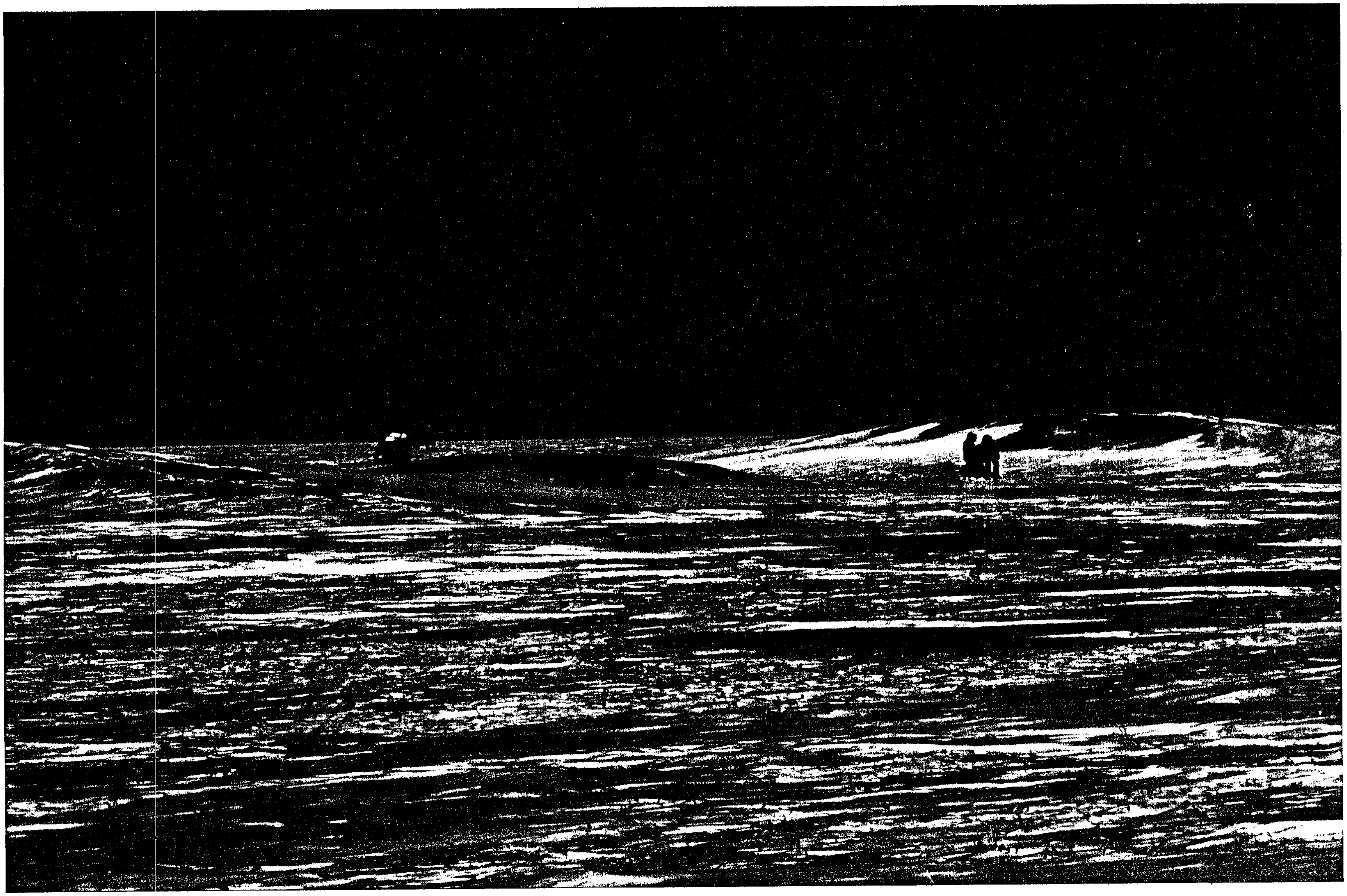

FIGURE 2.--Ice hummocks on the lower Sadlerochit River, March, 1988.

height of hummocks was measured to the nearest 0.1 ft using a hand held level laid on the highest point of the hummock. Height was then read from a surveyors leveling rod which was held on the level surface of adjacent river ice or exposed substrate.

Using a steam drill, a series of vertical holes were drilled in each hummock to develop a profile of the water pool. The drill used a 3 gal, propane fired boiler to produce steam that was released through a one inch outside diameter hose, attached to a 6 ft rigid fiberglass drill stem fitted with a pointed one inch brass tip drilled with seven 1/16 inch diameter holes. Holes in excess of one inch diameter were drilled through clear ice at rates exceeding 3 ft/min.

Holes were drilled along a hummock's long axis until water pool margins were determined. Additional holes were drilled along three perpendicular lines crossing the long axis at 25, 50, and 75 percent of the total length. Holes along these three lateral axes were drilled until the water pool margin was located on either side of the length axis. Depth from the ice surface to the bottom of the pool was measured to the nearest 0.1 ft using a fiberglass measuring tape with a 4 inch steel rod attached to the end. The rod was attached to the end of the tape at its midpoint so that it would catch the bottom of the ice when retrieved by the tape, measuring vertical ice thickness. Water depth was obtained by subtracting vertical ice thickness from the ice surface to pool bottom depth. A wire attached to one end of the rod was used to retrieve the rod and tape from the hole.

When possible, dissolved oxygen and electrical conductivity of water beneath the ice hummocks were measured using electronic meters.

A contour map of each pool was developed from water depth data. The area of each strata was measured using a planimeter. The total volume of the pool was then calculated using the following formula (Welch 1948):

$$V = \sum[h/3\ (a_1 + a_2 + \sqrt{a_1 a_2})]/0.1337\ \text{ft}^3/\text{gal}$$

where, V = volume (gal)
h = strata height (ft)
a_1 = area of top of strata (ft^2)
a_2 = area of bottom of strata (ft^2)

Linear, curve, and polynomial regression equations for pool volume versus three hummock size parameters (length, maximum height, and size coefficient) were determined. The dimensionless size coefficient is defined as the product of length and maximum height.

The regression equation with the highest correlation was used to estimate the water volume beneath all ice hummocks. Total water volume for each drainage was obtained by summing the pool volume estimates of each hummock in the drainage.

An inventory of the distribution and size of ice hummocks, excluding those within aufeis fields, was made using a helicopter. The number of river miles inventoried in each drainage were measured to the nearest 1.0 mi from 1:63,360 scale topographic maps using a map wheel. Flying along each river drainage, the locations of hummocks were determined with LORAN navigation equipment in the helicopter. The height and length of each ice hummock was visually estimated from the helicopter. Periodic stops were made to measure hummock height and length to ground truth visual estimations.

Ice hummock locations were plotted on 1:63,360 scale topographic maps from latitude and longitude coordinates recorded from the LORAN navigation unit. Location corrections were made by aligning an overlay map, registered to LORAN locations of known landmark locations, and by placing all locations within active floodplain boundaries.

Results

Water was found beneath seven of the nine ice hummocks drilled for pool volume estimation. The remaining two hummocks were frozen to the substrate. As few as 15 holes were drilled in the smallest hummock to as many as 35 holes in the larger hummocks. Hummock length and maximum height measurements ranged from 50 to 230 ft and from 3.0 to 10.6 ft, respectively (Table 1). Maximum measured water depths of the seven pools ranged from 0.3 to 5.8 ft.

Dissolved oxygen concentrations, measured in three of the seven pools, ranged from 0.2 to over 10.0 mg/l (Table 2). In addition to these three measurements, a dissolved oxygen concentration of 9.5 mg/l was measured beneath one ice hummock in the Sadlerochit River. Dissolved oxygen was not measured at all hummocks drilled because excessively cold and windy conditions reduced meter battery function to the point that meter response appeared to be questionable. Electrical conductivity could only be measured when the water beneath a hummock was under enough pressure to flow freely from the drill hole. Because of this constraint, conductivity was measured at only two of the seven pools located under the hummocks (Table 2).

Positive linear correlations were found between water pool volume and ice hummock height, length, and size coefficient. Hummock size coefficient was more strongly correlated with water volume ($r^2 = 0.77$) than either hummock length ($r^2 = 0.61$) or maximum height ($r^2 = 0.46$). The linear regression equation between pool volume and size coefficient provided the best fit to the data (Figure 3). The regression equation (Figure 3) relating volume in gallons (V) to size coefficient (C) was:

$$V = 38.16C - 8679.66$$

Visual estimates of maximum height and length were made for 604 ice hummocks found along the seven major river drainage systems in the 1002 area. Pool volume was estimated for each hummock using the linear regression equation of hummock size coefficient verses pool volume. The size parameter data and volume estimates for each hummock are presented in Appendix A. Based on 237 miles of river inventoried, a total of 8,839,200 gallons of water was estimated to occur beneath hummocks (Table 3). Based on an average requirement of 1,350,000 gal/mi/yr of ice road, the total water available in

TABLE 1.--Size parameters and calculated water volume of nine ice hummocks selected for study.

Drainage	Hummock Number	Maximum Height (ft)	Length (ft)	Size Coefficient	Water Volume (gal)
Tamayariak River	1	6.5	90	585	22,180
Katakturuk River	2	8.0	86	688	18,770
Sadlerochit River	3	10.6	75	795	35,690
Sadlerochit River	4	9.0	165	1,485	26,390
Sadlerochit River	5	7.8	230	1,794	72,440
Sadlerochit River	6	3.0	50	150	140
Jago River	7	5.1	60	306	170
Okerokovik River	8	3.4	95	323	0
Okerokovik River	9	4.8	110	528	0

TABLE 2.--Total dissolved oxygen and electrical conductivity measurements taken at selected ice hummocks and observation notes.

Drainage	Hummock Number	Dissolved Oxygen (mg/l)	Electrical Conductivity (umhos/cm)	Observation Notes
Tamayariak River	1	0.2	--	SO_2 odor.
Katakturuk River	2	> 10.0	--	Willow shrubs exposed at surface with water pool below.
Sadlerochit River	3	--	--	Gravel in ice @2.5 ft.
Sadlerochit River	4	8.5	690	Mud & gravel layer within ice @2 ft.
Sadlerochit River	5	--	--	Mud & gravel layer within ice @2 ft.
Sadlerochit River	6	--	--	Air space above water.
Jago River	7	--	12,000	Salty odor & extreme high pressure.
Okerokovik River	8	--	--	Dry, frozen to substrate. Rocks in ice.
Okerokovik River	9	--	--	Dry, frozen to substrate.

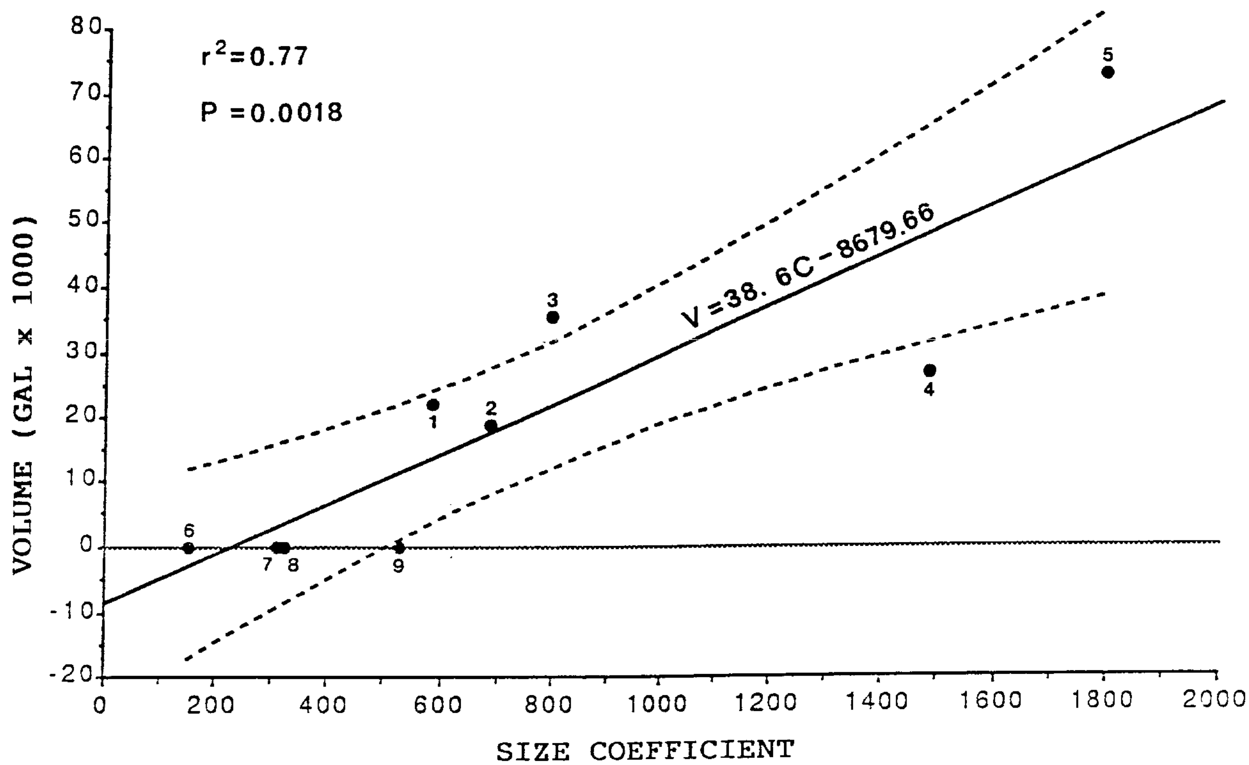

FIGURE 3.--Regression of ice hummock size coefficient versus water volume with the 95% confidence bounds for the true mean of Y. Data point numbers refer to hummock numbers on Table 1.

TABLE 3.--Data summary of ice hummock inventory by drainage system.

Drainage	Miles of River Surveyed	Ice Hummocks Observed (N)	Estimated Volume (gal)	Potential Miles of Ice Road
Canning River	35	138	1,861,000	1.4
Tamayariak River	34	45	438,100	0.3
Katakturuk River	23	60	829,200	0.6
Sadlerochit River	20	121	3,237,300	2.4
Hulahula River	25	165	2,100,600	1.6
Okpilak River	31	10	25,600	0.0
Jago River	69	65	447,400	0.3
TOTAL	237	604	8,939,200	6.6

the 237 river miles inventoried could support construction and maintenance of 6.6 mi of ice road.

Ice hummocks were widely distributed throughout the braided portions of the Canning, Tamayariak, Katakturuk, Sadlerochit, Hulahula, Okpilak, and Jago Rivers (Figures 4-9). The Niguanak and Angun Rivers were inspected for hummocks from their mouths upstream for 30 and 20 mi, respectively. No hummocks were observed on either river.

Discussion

Although winter water was found to occur over a widespread area in most of the major river drainages in the 1002 area, it was restricted to small isolated pools beneath ice hummocks scattered throughout the braided portions of these rivers. Are (1969) described the pool of water beneath a single ice hummock as hydraulically isolated. When the top of the hummock was cut into, the pressurized water contained beneath the ice rose into the excavated hole then stopped and froze over, indicating that the pool was not connected to a larger aquifer. The pools beneath some of the hummocks investigated during this study exhibited a similar response. Water was forced out of the initial drill hole but flow ceased after several minutes. One hummock was redrilled several days after the initial pool measurements were taken and there was no indication that any water pressure had built up over that time. It is unlikely that these isolated pools would become recharged if water were removed by any user.

Arcone et al. (1989) estimated pool volume beneath one ice hummock on the Sadlerochit River at 26,400 to 52,800 gal based on data collected with a helicopter mounted short impulse radar and a single measurement of water pool depth. Using their height and length measurements in the regression equation developed in this report, a pool volume estimate of 33,300 gal is obtained. The close agreement of these two estimates using two different methodologies during different years supports the transportability of the pool volume to size coefficient relationship to data collected in years other than 1989.

Knowledge of volume of water contained in pools beneath ice hummocks is critical in considering the area's potential for future large scale oil and gas exploration activities. Average water demands reported in the Prudhoe Bay area for oil and gas exploration are (Wilson et al. 1977; Clough et al. 1987);

Geophysical exploration	1,000 gpd/crew
Exploratory drilling	30,000 gpd/crew
Base camp (65 gpd/man x 75 men)..............	5,000 gpd/camp
Ice road construction and maintenance.........	1,350,000 gal/mi
Ice airstrip construction and maintenance.....	7,000,000 gal

where, gpd = gal per day

Within the 1002 area, 604 ice hummocks were found along a total of 237 miles of river channels. If the estimated 8.9 million gal of water found beneath the hummocks were used to construct ice roads for oil and gas exploration, a total of 6.6 mi of ice road could be constructed and

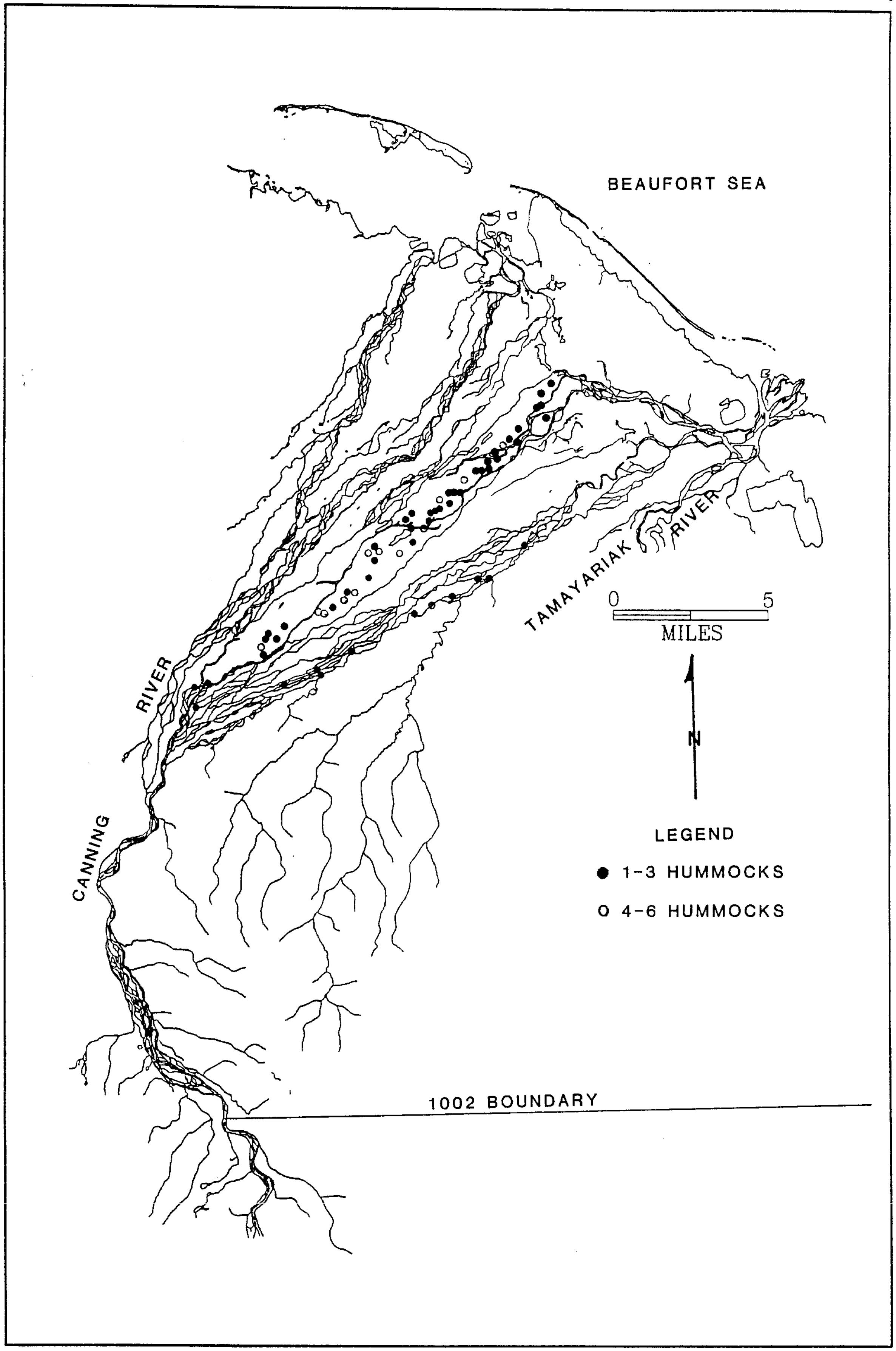

Figure 4.--Ice hummock locations in the Canning River drainage within the 1002 area, Arctic National Wildlife Refuge.

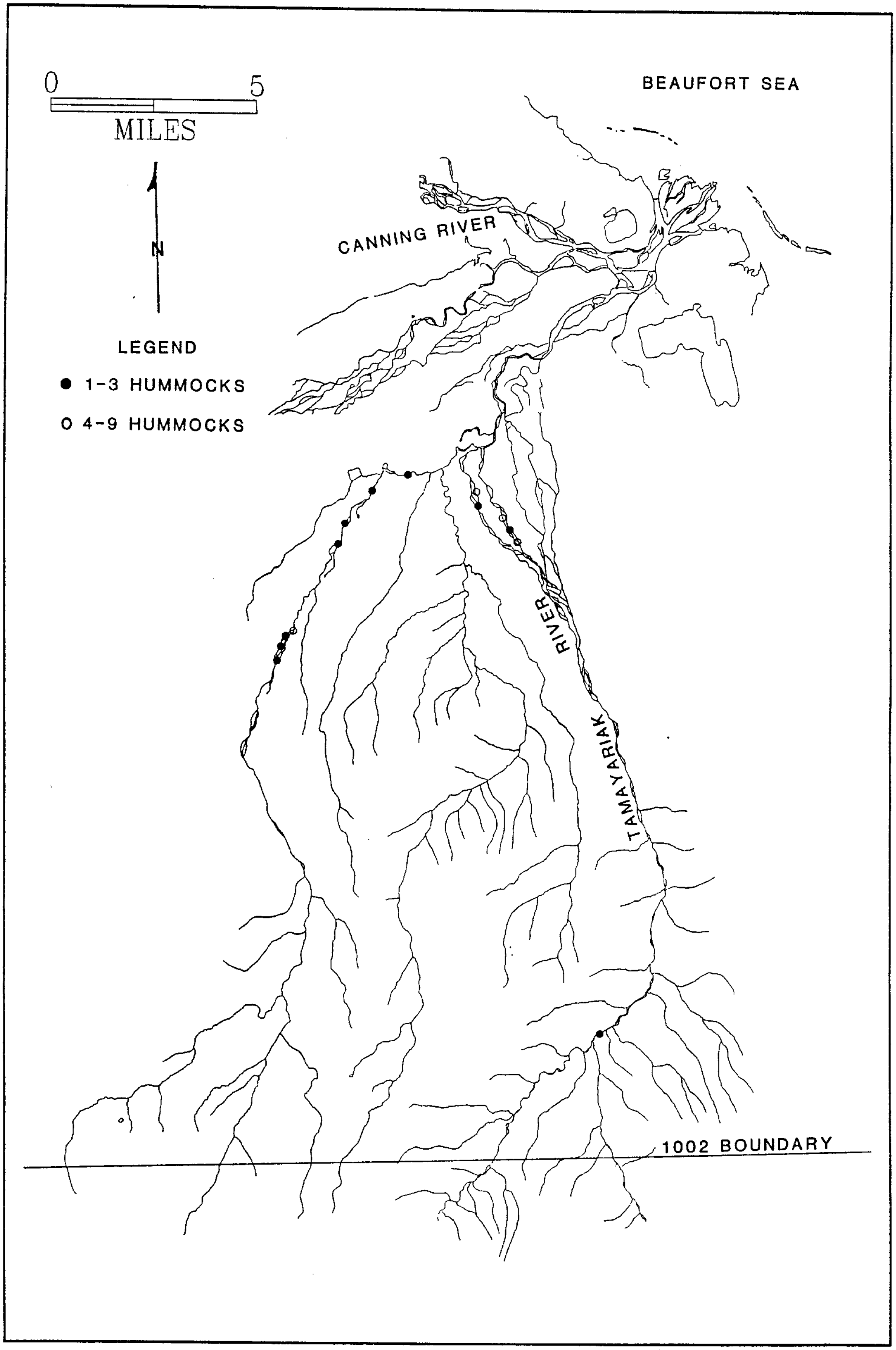

Figure 5.--Ice hummock locations in the Tamayariak River drainage within the 1002 area, Arctic National Wildlife Refuge.

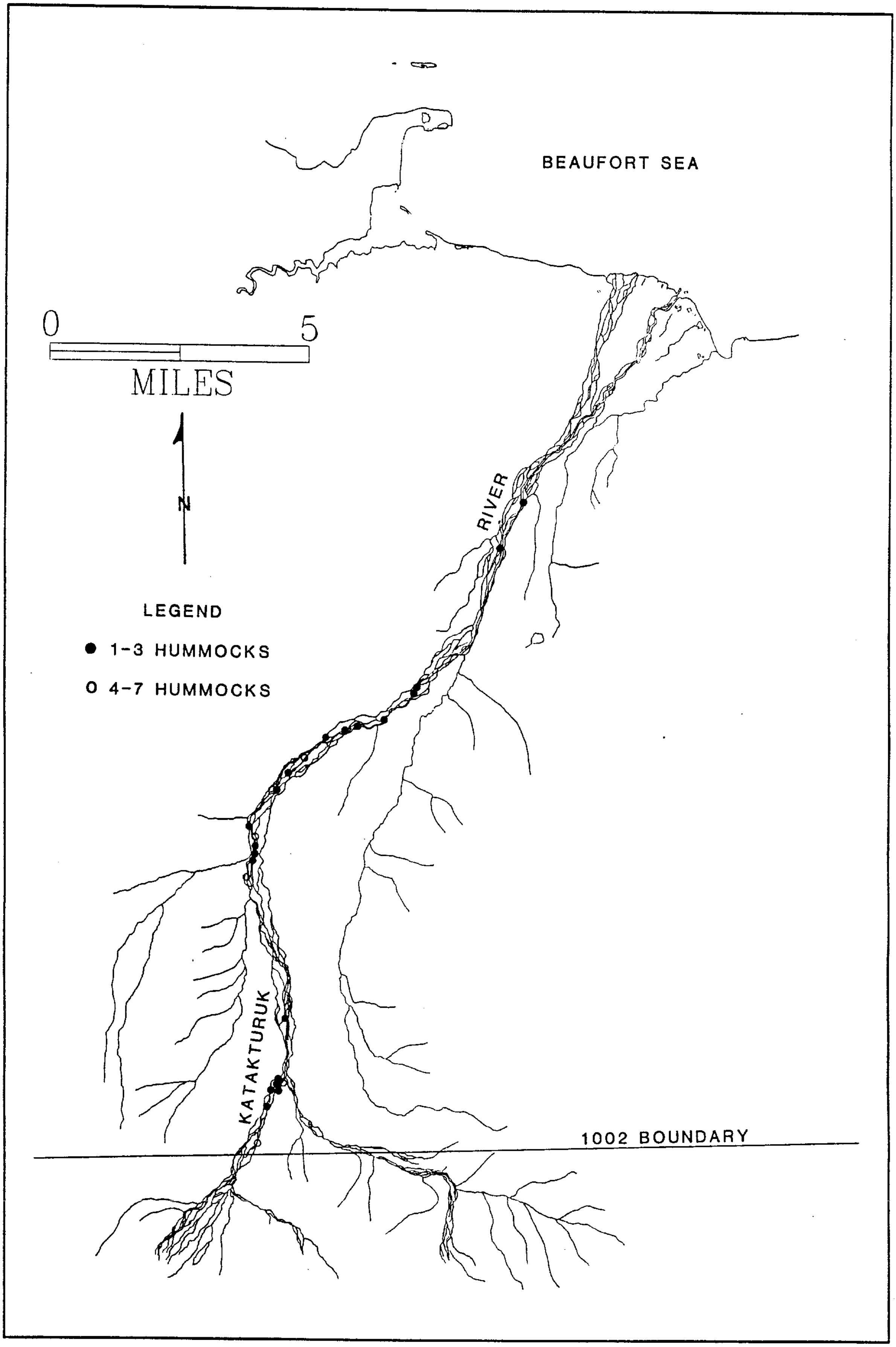

Figure 6.--Ice hummock locations in the Katakturuk River drainage within the 1002 area, Arctic National Wildlife Refuge.

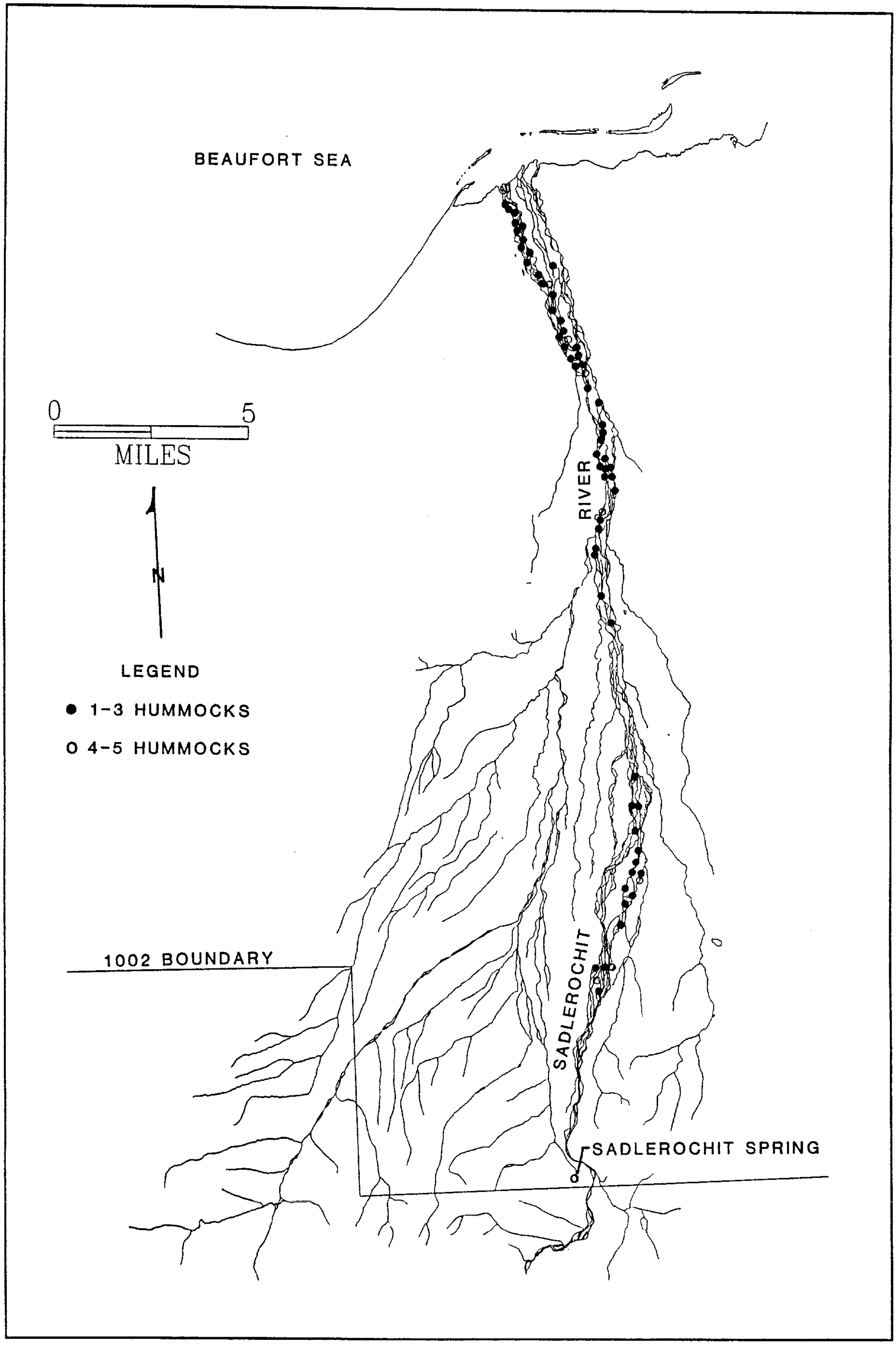

Figure 7.--Ice hummock locations in the Sadlerochit River drainage within the 1002 area, Arctic National Wildlife Refuge.

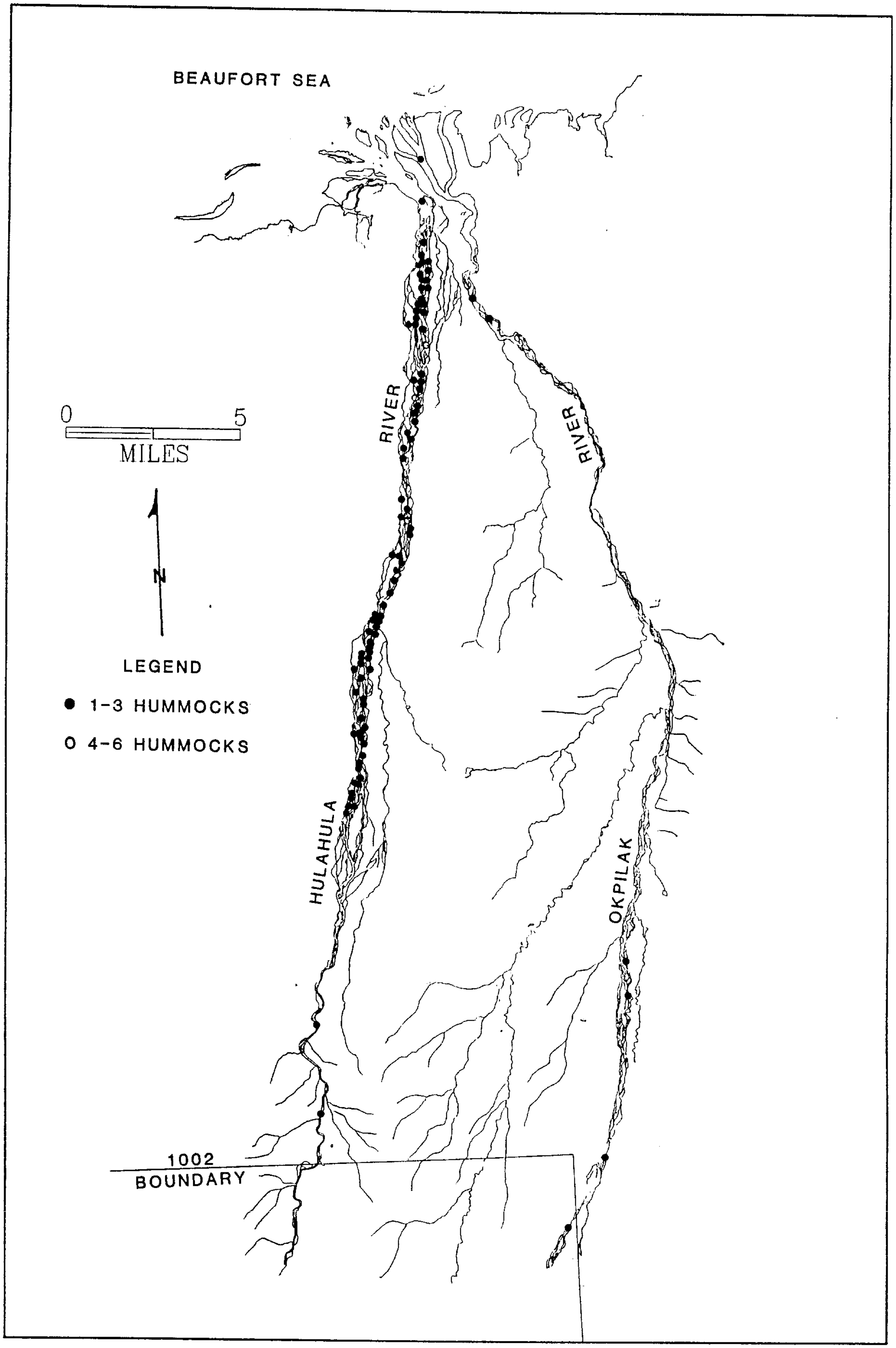

Figure 8.--Ice hummock locations in the Hulahula and Okpilak River drainages within the 1002 area, Arctic National Wildlife Refuge.

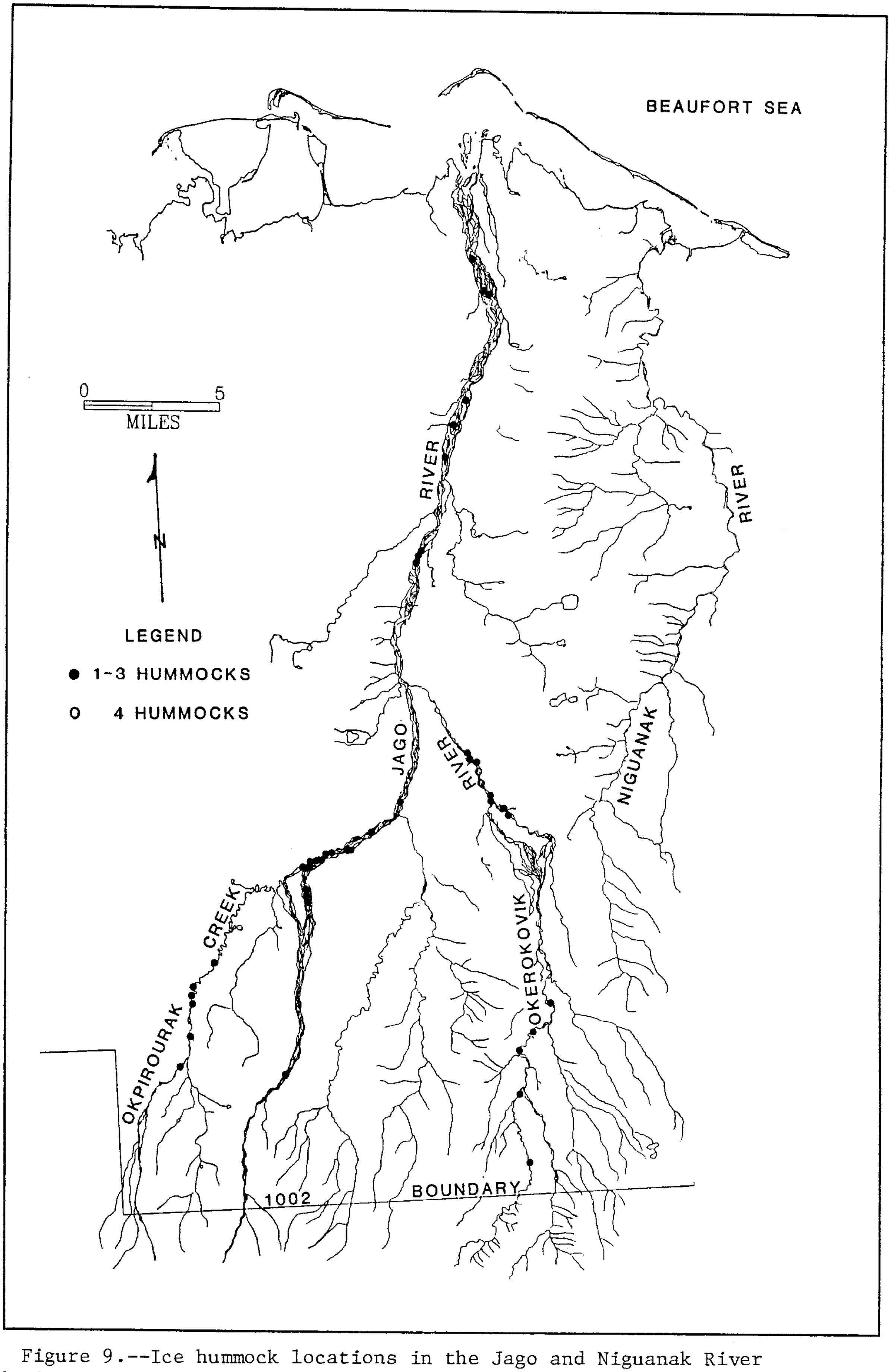

Figure 9.--Ice hummock locations in the Jago and Niguanak River drainages within the 1002 area, Arctic National Wildlife Refuge.

maintained. Ice thickness and water pool volumes may vary from year to year due to climatic factors.

Lakes provide a potentially more reliable source of water in the 1002 area than the water pools found along river sources (Elliott 1990). The estimated total amount of water available beneath all of the ice hummocks inventoried could be found beneath 4 ft of ice in 34 of the 52 lakes measured during 1989. The only other naturally occurring sources of winter water in the area are perennial springs. The largest spring in the 1002 area, Sadlerochit Spring, discharges an average of approximately 26 million gal per day (Lyons 1990).

Ice hummocks were also observed within all aufeisen identified within the 1002 area during this inventory. Alekseyev (1969) and Bukayev (1969) described the formation of hummocks within aufeisen (naleds) in Siberia. They proposed that the hummocks were the result of spring water that became pressurized when confined by layered naled ice and cracks in the hummocks were the points of release for water flowing to the naled surface. In addition to the seven aufeisen identified by Elliott (1989), another small icing was found on Okpirourak Creek in the Jago River drainage during this inventory. Hummocks observed within all aufeisen identified during 1989 were excluded from the inventory and volume measurements. It was assumed that the relationship used to estimate water pool volume for ice mounds over hydraulically isolated water pockets was different for ice mounds produced from the presence of flowing spring water.

Nekrasov (1969) described several ice hummocks in which layers of stream substrate were found within 6-12 inches of the ice surface. He postulated that hummocks formed over pools in the stream channel connected by subgravel flow which became pressurized from confinement between surface ice and frozen substrate. Two explanations were given to explain differences in the location and composition of substrate layers in the hummocks: 1) fine substrate particles were transported to the ice surface by pressurized water escaping through cracks over the deeper pools, and 2) coarser substrate was first contained in ice that froze to the stream bottom in shallower pools then was lifted by pressurized underground water. All ice hummocks described by Nekrasov (1969) were frozen to the substrate by mid May, as were two of the nine hummocks drilled during this study. In this study, four hummocks drilled for water pool delineation contained a layer of gravel and mud substrate approximately 2 ft from the ice surface. The location and composition of the substrate layers were closely approximated by the second explanation given by Nekrasov (1969), indicating a 2 ft layer of ice was frozen to the substrate when these hummocks began to form by lifting. Only one layer of gravel and mud substrate was observed in hummocks where this phenomenon occurred.

Water pressure beneath ice hummocks was reported to develop to the point where the stress resulted in the explosion of the top portion of the hummocks (Alekseyev 1969, Bogomolov and Sklyarevskaya 1969). One such explosion was heard nearly 4 mi away. Two of the water pools found beneath hummocks in this study were under enough pressure to force water out of the first hole drilled. One of these was under extremely high pressure, forcing water over 10 ft into the air.

Ice hummocks are not necessarily associated with deeper pools or scour holes within primary river channels. The hydrolaccoliths described by Bogomolov and Sklyarevskaya (1969) were subsurface ice hummocks that formed beneath a layer of sand and grass. During the present study, willow branches were observed protruding from the top of several hummocks. The presence of willows suggests that hummocks and water pockets are not confined to active channels but sometimes form on or along the margin of vegetated islands within highly braided drainage systems. During September, 1989, the locations of five of the ice hummock study sites were revisited. Two of the sites (hummocks 3 and 7) were located within main river channels. One (hummock 4) was located on a gravel bar adjacent to a main river channel. One (hummock 1) was located within a backwater pool formed at the confluence of a small side channel and a main river channel. The location of the largest hummock (hummock 5) was at the edge of a small side channel separated from the nonvegetated floodplain by a vegetated island. The last site appeared to be at the location of a low volume spring or emergence of intergravel flow.

All of the rivers where ice hummocks were found contain fish, but fish use beneath hummocks is not reported. It is not known if fish inhabit the water pockets beneath ice hummocks. The only reported overwinter habitat used by fish within the 1002 area is associated with perennial springs. However, water beneath several of the hummocks was of suitable quality and quantity to provide overwinter habitat for fish.

There is a relatively small quantity of water beneath ice hummocks within river systems of the 1002 area. Future studies of potential winter water sources would be of more value if directed toward lakes and temporary reservoirs as potential sources of winter water.

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Appendix

Ice Hummock Measurements and Water Volume Estimates

Canning River ice hummock inventory data and water volume estimates, April 1989.

Height (ft)	Length (ft)	Coeff (C)	Estim Volume (gal)	Height (ft)	Length (ft)	Coeff (C)	Estim Volume (gal)
4	20	80	0	6	50	300	2,767
4	20	80	0	6	50	300	2,767
4	20	80	0	6	50	300	2,767
4	20	80	0	6	50	300	2,767
4	20	80	0	6	50	300	2,767
4	20	80	0	7	50	350	4,675
3	30	90	0	7	50	350	4,675
5	20	100	0	7	50	350	4,675
6	20	120	0	9	40	360	5,057
6	20	120	0	9	40	360	5,057
4	30	120	0	6	60	360	5,057
4	30	120	0	6	60	360	5,057
4	30	120	0	6	60	360	5,057
4	30	120	0	6	60	360	5,057
5	30	150	0	6	60	360	5,057
5	30	150	0	8	50	400	6,583
5	30	150	0	8	50	400	6,583
4	40	160	0	8	50	400	6,583
6	30	180	0	5	80	400	6,583
6	30	180	0	5	80	400	6,583
6	30	180	0	5	80	400	6,583
6	30	180	0	4	100	400	6,583
6	30	180	0	7	60	420	7,346
6	30	180	0	7	60	420	7,346
5	40	200	0	7	60	420	7,346
5	40	200	0	7	60	420	7,346
5	40	200	0	6	70	420	7,346
5	40	200	0	9	50	450	8,491
5	40	200	0	5	90	450	8,491
5	40	200	0	8	60	480	9,636
4	50	200	0	6	80	480	9,636
4	50	200	0	6	80	480	9,636
4	50	200	0	6	80	480	9,636
7	30	210	0	6	80	480	9,636
6	40	240	478	5	100	500	10,399
6	40	240	478	5	100	500	10,399
6	40	240	478	9	60	540	11,925
6	40	240	478	8	70	560	12,688
5	50	250	860	6	100	600	14,215
5	50	250	860	6	100	600	14,215
5	50	250	860	6	100	600	14,215
5	50	250	860	6	100	600	14,215
7	40	280	2,004	6	100	600	14,215
7	40	280	2,004	6	100	600	14,215
7	40	280	2,004	9	70	630	15,359
7	40	280	2,004	7	90	630	15,359
7	40	280	2,004	7	90	630	15,359
7	40	280	2,004	7	90	630	15,359

Canning River (continued)

Height (ft)	Length (ft)	Coeff (C)	Estim Volume (gal)
8	80	640	15,741
8	80	640	15,741
7	100	700	18,030
7	100	700	18,030
7	100	700	18,030
7	100	700	18,030
7	100	700	18,030
7	100	700	18,030
7	100	700	18,030
7	100	700	18,030
9	80	720	18,793
9	80	720	18,793
8	90	720	18,793
6	120	720	18,793
5	150	750	19,938
8	100	800	21,846
8	100	800	21,846
9	90	810	22,228
7	120	840	23,372
7	120	840	23,372
10	90	900	25,662

Height (ft)	Length (ft)	Coeff (C)	Estim Volume (gal)
9	100	900	25,662
6	150	900	25,662
6	150	900	25,662
6	150	900	25,662
6	150	900	25,662
8	120	960	27,951
5	200	1,000	29,477
7	150	1,050	31,385
8	150	1,200	37,109
6	200	1,200	37,109
9	150	1,350	42,832
9	150	1,350	42,832
7	200	1,400	44,740
8	180	1,440	46,266
6	250	1,500	48,556
8	200	1,600	52,372
8	200	1,600	52,372
8	250	2,000	67,634
9	250	2,250	77,174
8	400	3,200	113,423
7	600	4,200	151,580

Tamayariak River ice hummock inventory data and water volume estimates, April 1989.

Height (ft)	Length (ft)	Coeff (C)	Estim Volume (gal)
2	40	80	0
2	40	80	0
2	40	80	0
2	40	80	0
2	50	100	0
2	50	100	0
4	30	120	0
4	40	160	0
4	50	200	0
4	50	200	0
4	50	200	0
4	50	200	0
2	100	200	0
6	40	240	478
4	60	240	478
8	30	240	478
5	50	250	860
8	35	280	2,004
6	50	300	2,767
6	50	300	2,767
6	50	300	2,767
6	50	300	2,767
6	50	300	2,767

Height (ft)	Length (ft)	Coeff (C)	Estim Volume (gal)
6	50	300	2,767
7	50	350	4,675
6	60	360	5,057
6	60	360	5,057
4	90	360	5,057
6	60	360	5,057
8	50	400	6,583
7	60	420	7,346
5	100	500	10,399
4	200	800	21,846
8	100	800	21,846
8	100	800	21,846
8	100	800	21,846
8	100	800	21,846
8	100	800	21,846
8	100	800	21,846
8	100	800	21,846
8	100	800	21,846
8	100	800	21,846
6	150	900	25,662
8	200	1,600	52,372
7	300	2,100	71,450

Katakturuk River ice hummock inventory data and water volume estimates, April 1989.

Height (ft)	Length (ft)	Coeff (C)	Estim Volume (gal)
4	20	80	0
4	20	80	0
6	30	180	0
6	30	180	0
4	50	200	0
4	50	200	0
4	50	200	0
4	50	200	0
4	50	200	0
4	50	200	0
4	50	200	0
5	40	200	0
6	40	240	478
4	60	240	478
6	50	300	2,767
6	50	300	2,767
6	50	300	2,767
6	50	300	2,767
6	50	300	2,767
6	50	300	2,767
6	50	300	2,767
6	50	300	2,767
6	60	360	5,057
6	60	360	5,057
4	100	400	6,583
5	80	400	6,583
6	70	420	7,346
6	80	480	9,636
6	80	480	9,636
6	80	480	9,636

Height (ft)	Length (ft)	Coeff (C)	Estim Volume (gal)
6	80	480	9,636
5	100	500	10,399
5	100	500	10,399
4	150	600	14,215
6	100	600	14,215
8	80	640	15,741
7	100	700	18,030
7	100	700	18,030
7	100	700	18,030
9	80	720	18,793
5	150	750	19,938
5	150	750	19,938
5	150	750	19,938
8	100	800	21,846
8	100	800	21,846
8	100	800	21,846
10	80	800	21,846
8	100	800	21,846
8	100	800	21,846
4	200	800	21,846
4	200	800	21,846
6	150	900	25,662
9	100	900	25,662
9	100	900	25,662
8	150	1,200	37,109
6	200	1,200	37,109
7	200	1,400	44,740
10	150	1,500	48,556
8	200	1,600	52,372
10	200	2,000	67,634

Sadlerochit River ice hummock inventory data and water volume estimates, April 1989.

Height (ft)	Length (ft)	Coeff (C)	Estim Volume (gal)
4	30	120	0
4	40	160	0
4	50	200	0
4	50	200	0
4	50	200	0
4	50	200	0
4	50	200	0
5	40	200	0
5	40	200	0
7	30	210	0
6	40	240	478
5	60	300	2,767
5	60	300	2,767
3	100	300	2,767
6	50	300	2,767
5	60	300	2,767
6	50	300	2,767
4	80	320	3,531
4	80	320	3,531
4	80	320	3,531
4	80	320	3,531
7	50	350	4,675
6	60	360	5,057
5	80	400	6,583
4	100	400	6,583
4	100	400	6,583
5	80	400	6,583
6	70	420	7,346
6	70	420	7,346
6	70	420	7,346
7	60	420	7,346
5	90	450	8,491
6	80	480	9,636
8	60	480	9,636
6	80	480	9,636
7	70	490	10,017
5	100	500	10,399
5	100	500	10,399
5	100	500	10,399
5	100	500	10,399
6	90	540	11,925
6	90	540	11,925
7	80	560	12,688
7	80	560	12,688
7	80	560	12,688
8	70	560	12,688
4	150	600	14,215
6	100	600	14,215
5	120	600	14,215
7	90	630	15,359
7	90	630	15,359
7	90	630	15,359
9	70	630	15,359
8	80	640	15,741
8	80	640	15,741
8	80	640	15,741
7	100	700	18,030
9	80	720	18,793
6	120	720	18,793
6	120	720	18,793
5	150	750	19,938
5	150	750	19,938
5	150	750	19,938
10	80	800	21,846
7	120	840	23,372
11	80	880	24,898
9	100	900	25,662
6	150	900	25,662
9	100	900	25,662
6	150	900	25,662
6	150	900	25,662
8	120	960	27,951
8	120	960	27,951
8	120	960	27,951
8	120	960	27,951
7	140	980	28,714
5	200	1,000	29,477
5	200	1,000	29,477
10	100	1,000	29,477
10	100	1,000	29,477
7	150	1,050	31,385
7	150	1,050	31,385
7	150	1,050	31,385
8	150	1,200	37,109
8	150	1,200	37,109
6	200	1,200	37,109
8	150	1,200	37,109
6	200	1,200	37,109
12	100	1,200	37,109
10	120	1,200	37,109
4	300	1,200	37,109
8	150	1,200	37,109
6	200	1,200	37,109
4	300	1,200	37,109

Sadlerochit River (continued)

Height (ft)	Length (ft)	Coeff (C)	Estim Volume (gal)
10	120	1,200	37,109
5	250	1,250	39,017
5	250	1,250	39,017
9	150	1,350	42,832
9	150	1,350	42,832
8	180	1,440	46,266
5	300	1,500	48,556
8	200	1,600	52,372
8	200	1,600	52,372
8	200	1,600	52,372
8	200	1,600	52,372
7	250	1,750	58,095
9	200	1,800	60,003
9	200	1,800	60,003

Height (ft)	Length (ft)	Coeff (C)	Estim Volume (gal)
8	250	2,000	67,634
10	200	2,000	67,634
8	250	2,000	67,634
5	400	2,000	67,634
8	250	2,000	67,634
7	300	2,100	71,450
8	300	2,400	82,897
8	300	2,400	82,897
7	350	2,450	84,805
7	350	2,450	84,805
5	500	2,500	86,713
12	250	3,000	105,791
9	350	3,150	111,515

Hulahula River ice hummock inventory data and water volume estimates, April 1989.

Height (ft)	Length (ft)	Coeff (C)	Estim Volume (gal)
2	15	30	0
2	20	40	0
3	15	45	0
4	15	60	0
4	15	60	0
4	15	60	0
3	20	60	0
3	20	60	0
4	20	80	0
4	20	80	0
3	30	90	0
3	30	90	0
5	20	100	0
6	20	120	0
4	30	120	0
4	30	120	0
4	30	120	0
4	30	120	0
4	30	120	0
4	30	120	0
4	30	120	0
3	40	120	0
3	40	120	0
5	30	150	0
5	30	150	0
3	50	150	0
4	40	160	0
4	40	160	0
4	40	160	0
4	40	160	0
4	40	160	0
4	40	160	0
4	40	160	0
4	40	160	0
6	30	180	0
6	30	180	0
6	30	180	0
5	40	200	0
5	40	200	0
4	50	200	0
3	70	210	0
3	70	210	0
6	40	240	478
6	40	240	478
4	60	240	478
4	60	240	478
3	80	240	478
5	50	250	860

Height (ft)	Length (ft)	Coeff (C)	Estim Volume (gal)
5	50	250	860
3	90	270	1,623
7	40	280	2,004
4	70	280	2,004
6	50	300	2,767
6	50	300	2,767
6	50	300	2,767
6	50	300	2,767
5	60	300	2,767
5	60	300	2,767
3	100	300	2,767
8	40	320	3,531
4	80	320	3,531
4	80	320	3,531
4	80	320	3,531
7	50	350	4,675
7	50	350	4,675
5	70	350	4,675
9	40	360	5,057
4	90	360	5,057
4	90	360	5,057
3	120	360	5,057
8	50	400	6,583
8	50	400	6,583
8	50	400	6,583
5	80	400	6,583
5	80	400	6,583
5	80	400	6,583
5	80	400	6,583
5	80	400	6,583
4	100	400	6,583
4	100	400	6,583
7	60	420	7,346
7	60	420	7,346
7	60	420	7,346
6	70	420	7,346
6	70	420	7,346
9	50	450	8,491
9	50	450	8,491
9	50	450	8,491
5	90	450	8,491
8	60	480	9,636
8	60	480	9,636
6	80	480	9,636
6	80	480	9,636
6	80	480	9,636
6	80	480	9,636
4	120	480	9,636

Hulahula River (continued)

Height (ft)	Length (ft)	Coeff (C)	Estim Volume (gal)
4	120	480	9,636
7	70	490	10,017
5	100	500	10,399
5	100	500	10,399
5	100	500	10,399
9	60	540	11,925
6	90	540	11,925
6	90	540	11,925
6	90	540	11,925
6	90	540	11,925
8	70	560	12,688
8	70	560	12,688
7	80	560	12,688
7	80	560	12,688
4	140	560	12,688
6	100	600	14,215
6	100	600	14,215
5	120	600	14,215
5	120	600	14,215
5	120	600	14,215
4	150	600	14,215
7	90	630	15,359
7	90	630	15,359
7	100	700	18,030
8	90	720	18,793
6	120	720	18,793
6	120	720	18,793
4	180	720	18,793
5	150	750	19,938
5	150	750	19,938
8	100	800	21,846
8	100	800	21,846
8	100	800	21,846
8	100	800	21,846
4	200	800	21,846

Height (ft)	Length (ft)	Coeff (C)	Estim Volume (gal)
7	120	840	23,372
7	120	840	23,372
7	120	840	23,372
6	140	840	23,372
6	150	900	25,662
6	150	900	25,662
6	150	900	25,662
6	150	900	25,662
5	180	900	25,662
8	120	960	27,951
8	120	960	27,951
8	120	960	27,951
8	130	1,040	31,004
7	150	1,050	31,385
9	120	1,080	32,530
6	180	1,080	32,530
10	120	1,200	37,109
8	150	1,200	37,109
6	200	1,200	37,109
4	300	1,200	37,109
5	250	1,250	39,017
7	200	1,400	44,740
7	200	1,400	44,740
7	200	1,400	44,740
7	200	1,400	44,740
7	200	1,400	44,740
5	300	1,500	48,556
8	200	1,600	52,372
8	200	1,600	52,372
9	180	1,620	53,135
7	250	1,750	58,095
7	250	1,750	58,095
6	300	1,800	60,003
6	300	1,800	60,003

Okpilak River ice hummock inventory data and water volume estimates, April 1989.

Height (ft)	Length (ft)	Coeff (C)	Estim Volume (gal)
2	20	40	0
2	30	60	0
3	20	60	0
3	40	120	0
3	50	150	0

Height (ft)	Length (ft)	Coeff (C)	Estim Volume (gal)
4	40	160	0
4	40	160	0
4	40	160	0
3	70	210	0
6	150	900	25,662

Jago River ice hummock inventory data and water volume estimates, April 1989.

Height (ft)	Length (ft)	Coeff (C)	Estim Volume (gal)
3	15	45	0
3	20	60	0
3	20	60	0
3	20	60	0
2	30	60	0
4	20	80	0
4	20	80	0
4	20	80	0
4	20	80	0
2	40	80	0
4	30	120	0
4	30	120	0
4	30	120	0
4	30	120	0
3	40	120	0
3	40	120	0
3	50	150	0
3	50	150	0
3	50	150	0
3	50	150	0
3	50	150	0
3	50	150	0
4	40	160	0
3	60	180	0
5	40	200	0
4	50	200	0
4	50	200	0
4	60	240	478
4	60	240	478
4	60	240	478
3	80	240	478
3	80	240	478
5	50	250	860

Height (ft)	Length (ft)	Coeff (C)	Estim Volume (gal)
4	70	280	2,004
6	50	300	2,767
5	60	300	2,767
3	100	300	2,767
4	80	320	3,531
7	50	350	4,675
7	50	350	4,675
5	70	350	4,675
5	70	350	4,675
4	90	360	5,057
8	50	400	6,583
5	80	400	6,583
5	80	400	6,583
5	80	400	6,583
9	50	450	8,491
5	90	450	8,491
3	150	450	8,491
6	80	480	9,636
5	100	500	10,399
5	100	500	10,399
7	80	560	12,688
6	100	600	14,215
5	120	600	14,215
6	120	720	18,793
5	150	750	19,938
4	200	800	21,846
5	180	900	25,662
5	200	1,000	29,477
8	150	1,200	37,109
4	300	1,200	37,109
7	200	1,400	44,740
6	250	1,500	48,556