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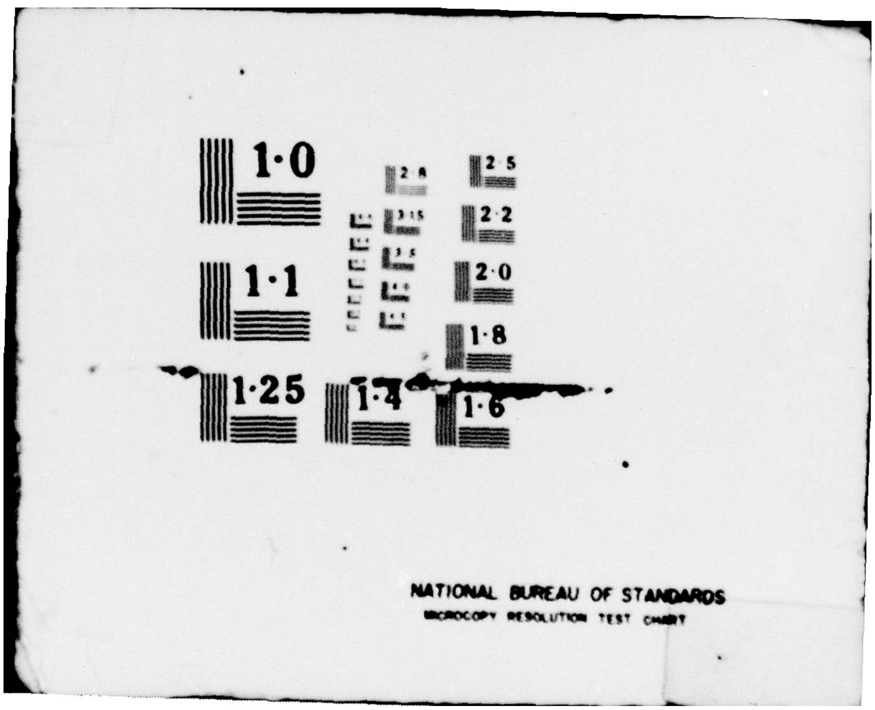
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TUNDRA LAKES AS A SOURCE OF FRESH WATER: KIPNUK, ALASKA.

Stephen R. Bredthauer and Duane F. Doerflinger

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A study of water quality in several small tundra lakes near Kipnuk, Alaska, was conducted to determine if the lakes were of sufficiently high quality during the snowmelt season to provide the village with enough water for a year-round supply. Since the village is located just 4 miles inland from the Bering Sea, primary emphasis was placed on locating water sources with low chloride concentrations. The tundra lakes were of sufficiently high quality to be pumped into a storage area during early summer to be used as a year-round supply.

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PREFACE

This report was prepared by Stephen R. Bredthauer, Research Civil Engineer, and Duane F. Doerflinger, Engineering Technician, of the Alaskan Projects Office, U.S. Army Cold Regions Research and Engineering Laboratory.

The study covered by this report was performed under U.S. Public Health Service Contract No. 243-76-0206, Amendment No. 2, *Kipnuk Water Source Study*.

This report was technically reviewed by Dr. I.K. Iskandar and P.V. Sellmann of CRREL.

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TUNDRA LAKES AS A SOURCE OF FRESH WATER: KIPNUK, ALASKA

Stephen R. Bredthauer and Duane F. Doerflinger

Introduction

A study of water quality in several small tundra lakes near Kipnuk, Alaska, was conducted for the U.S. Public Health Service by CRREL to determine if the lakes were of sufficiently high quality to provide the village with a year-round water supply. Since the village is located near the Bering Sea, primary emphasis was placed on locating water sources with low chloride concentrations.

Kipnuk (Fig. 1) is located on the Kuguklik River in the Yukon-Kuskokwim Delta area of southwest Alaska, approximately 4 miles from the Bering Sea. The surrounding area is low and marshy, with numerous small brackish lakes. The village is within the Transition Climatic Zone (Fig. 2) with a mean annual temperature of 30 F and mean annual precipitation of 20 in. Balding (1976) reports that occasional summer storms develop or move into the Bering Sea, creating strong onshore winds along the western coast and fequently resulting in flooding of low-lying coastal areas.

Balding (1976) has estimated suspended-sediment concentrations in surface waters in the region around Kipnuk to be less than 100 mg/l, and that observed dissolved-solids concentrations of surface water in the subarea are less than 200 mg/l. Water temperature ranges from 32^{o}F to 40^{o}F for groundwater. Chemical analysis of ground and lake water at Kipnuk is presented in Table 1.

It has been hypothesized that during the breakup season the melting snow and ice would form a freshwater layer over the brackish water in the coastal lakes near Kipnuk, and that the freshwater zone would last long enough so that it could be pumped into a storage area for year-round use bv the villagers. An initial field reconnaissance indicated that chloride concentrations in the lake ice were in the 0-50 ppm range and that enough snow and ice was available to dilute any remaining brackish water to potable levels (<250 ppm chloride). Studies were initiated to determine chloride profiles of the lakes during snowmelt, and to determine the amount of potable water and the length of time that it was available. In addition, the process which eventually turns the lakes from fresh water to brackish water was to be determined.

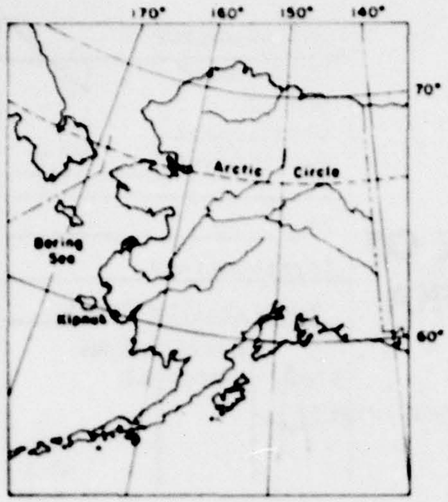


Figure 1. Location map - Kipnuk, Alaska.

Literature Review of Desalination by Natural Freezing

Desalination of water by freezing has long been accepted as a viable process to improve water quality, and has been practiced by the inhabitants of Siberia for generations. The freeze desalination of sea ice is the classic natural process. Weeks and Lee (1962) found that the salinity of young sea ice decreases from approximately 20,000 parts per million (ppm) immediately after its formation to 5,000 ppm after 2-4 weeks. Weeks and Lofgren (1966) determined that sea ice becomes nearly salt-free after a few years. Bennington (1967), in a study of salinity profiles of young sea ice, determined that young sea ice can form with salinities as low as 12%-15% of the sea water from which it was formed. Untersteiner (1968) concluded that the possible mechanisms of natural sea ice desalination are the flushing or washing-out of brine by surface meltwater and the expulsion of brine by volume changes during cooling periods.

As brackish lakes freeze and salts are excluded from the ice, the salinity of the water beneath the ice cover will increase. In a study of the limnology of Imikpuk Lake near Point Barrow, Boyd (1959) observed a significant increase in NaCl concentrations (Fig. 3) beneath the ice cover as winter progressed, followed by a sharp reduction in concentrations during the period of ice melt.

Kingery et al. (1960) reported the results from studies of variables which affect the rate of formation of ice, its structure, and its salinity when formed from ponds, by either rapid or slow solidification from rapidly moving streams, and from sprays. Ice formed from pond-solidification of sea water in 6 to 9-in.-deep reservoirs was collected after obtaining ice thicknesses of 1 to 6 in. The ice was found to have an average salinity of approximately 2,000 ppm for samples thicker than 1-in. Freezing under rapid rates of fluid flow was found to be too slow a desalination technique for practical field use. Pressure desalination was also deemed impractical for field use due to the small amount of water which could be treated.

The Saskatchewan Research Council initiated research on desalination by natural freezing in 1960 in order to find a means of desalinating brackish groundwater to provide a water supply source for small communities. Three processes were studied--reservoir freezing, layer freezing, and spray freezing-- and the results were presented in articles by Fertuck et al. (1970, 1971) and Spyker and Husband (1973). Desalination by reservoir freezing was shown to be a simple, economical process in which brackish water is pumped into a reservoir in autumn and allowed to freeze, with most of the dissolved solids concentrating in the brine beneath the ice. The brine was removed in spring before the ice melted. Reductions in ice salinities of 70-85% were achieved.

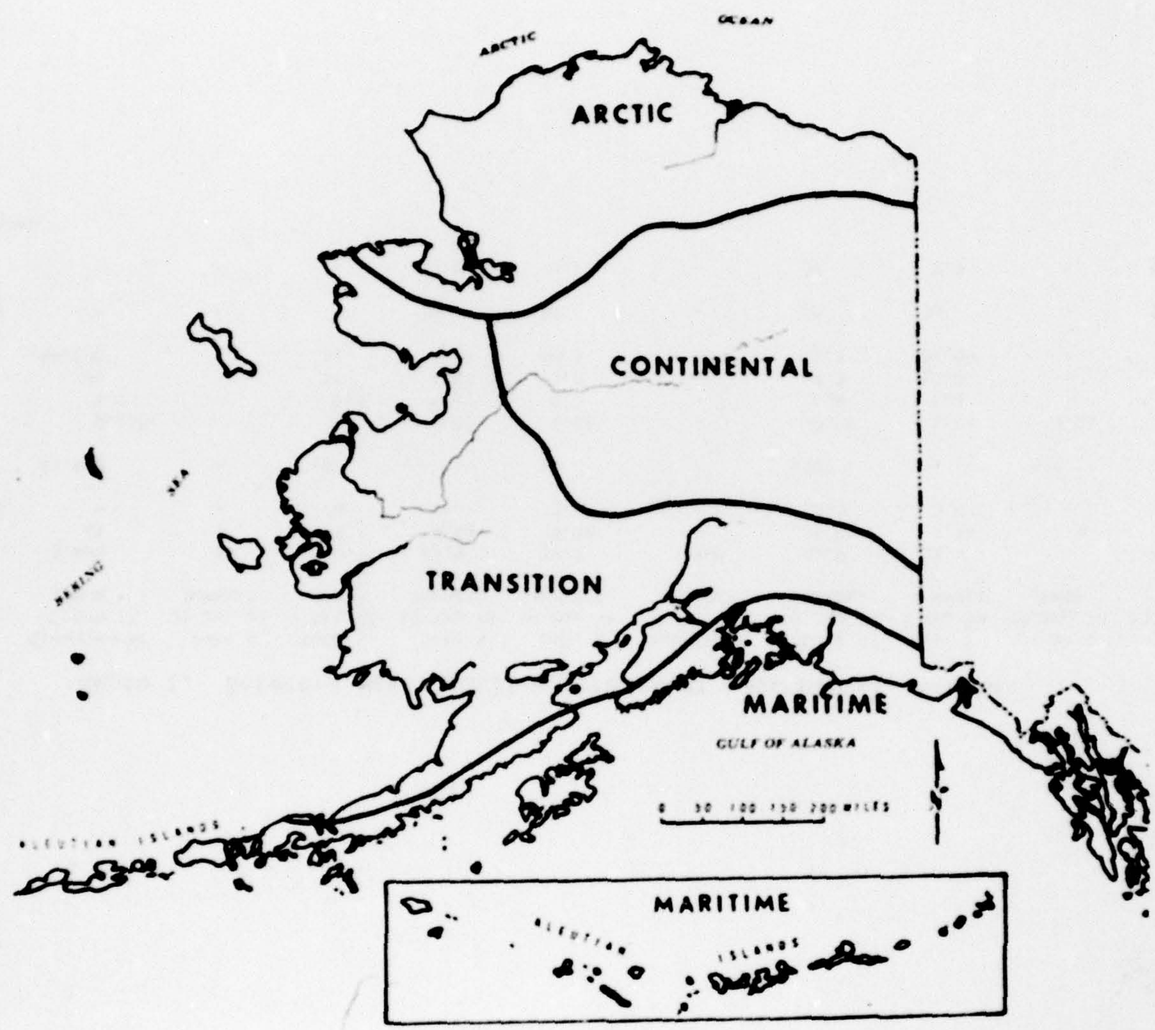


Figure 2. Climatic zones of Alaska.

Table 1. Selected water quality parameters near Kipnuk, Alaska.

	Groundwater 26 Feb 72 (USGS)*	Lake A 21 Jun 77 (CRREL)	Lake A 4 Oct 77 (PHS)	Lake A 12 May 78 (CRREL)	Lake A 24 May 78 (CRREL)	Kuguklik R. 24 May 78 (CRREL)	Lake A 13 Jun 78 (CRREL)	Lake A 3 Aug 78 (CRREL)	Lake C 21 Aug 78 (PHS)	Lake C 13 Sep 78 (PHS)
Chloride (mg/l)	5,880	55	150	23.5	30.7	5700	62.8	94.0	-	110
Iron (mg/l)	11	-	1.2	0.42	0.59	-	1.81	1.21	1.9	-
Alkalinity (mg/l) as $CaCO_3$	-	-	28	-	3.3	-	3.2	1.8	-	8
Total dissolved solids (mg/l)	11,100	-	267	-	33	-	132	211	330	204
Manganese (mg/l)	0.250	-	-	0.03	0.01	-	0.01	0.01	0.05	-
pH	8.0	-	5.8	9.0	6.3	-	5.8	6.3	-	5.9
Sulfate (mg/l)	63	-	18	1.50	3.2	-	4.3	13.0	-	22
Hardness (mg/l) as $CaCO_3$	18,100	-	31	8.18	10.3	-	13.3	21.98	-	40
Color (true color units)	-	-	-	18	32	-	50	70	-	120
Turbidity (NTU)	-	-	-	2.5	4.7	-	36	7.0	-	400

*From Balding (1976).

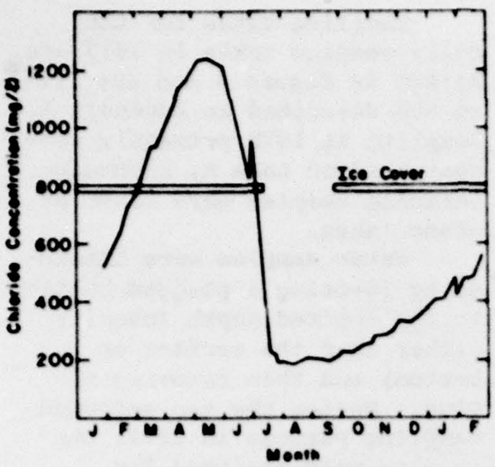


Figure 3. Seasonal changes in the chloride concentration of Imikpuk Lake, Pt. Barrow, Alaska (Boyd 1959).

Studies were also conducted on the effect of snow cover on ice salinity. Less ice was formed under a snow cover, but this was offset by increased purity of the ice as well as additional fresh water input from snowmelt. It was also determined that unlined reservoirs could be used as distilling basins; if seepage were high, salts excluded from the ice would seep out with the brine and reduce salinity build-up beneath the ice. Since freezing of the reservoirs depended on natural freezing processes, with the purified water becoming available only once per year, a large storage reservoir is required to hold the desalted water for year-round use.

Layer freezing is a more complex process in which a block of ice is built up during the winter by freezing successive layers of saline water on top of existing ice. During the melt season, the initial meltwater containing most of the salts is drained off, and the remaining ice is melted and stored as potable water. Recovery rates greater than 70% have been achieved using 5,000-ppm NaCl solutions. Engineering problems such as proper water distribution and flotation of previously frozen ice were encountered. This method appeared more expensive than reservoir freezing.

Spray freezing is a process in which saline water is sprayed or sprinkled continuously onto an unconfined apron. Brine drainage begins almost immediately and continues throughout the winter. The brine drainage and the initial meltwater are discarded, and the remaining ice melt collected for a water source. The salinity is controlled by discarding more or less of the initial melt. While similar to layer freezing, spray freezing has several advantages contributing to lower costs. These advantages include: 1) no retaining walls are required for the ice block, 2) only a relatively small steady source of feed water is required, and 3) none of the engineering problems of layer freezing, such as proper water distribution and flotation of previously frozen ice, are encountered. Results of a spray freezing experiment indicated that 85% of the input water at 4500-ppm sodium chloride solution could be recovered as water containing less than 1000 ppm sodium chloride. A modified rotary sprinkler, similar to a rotary lawn sprinkler, was used to spray the saline water, with no major problems encountered.

Sampling Sites and Procedures

Water quality of lakes near Kipnuk was monitored from April 1977 until September 1978. Several lakes were sampled at least daily during the periods 17-25 May 1977 and 8-22 June 1977. The day-to-day variation was so minor during the above periods that additional sampling was reduced to periodic sampling.

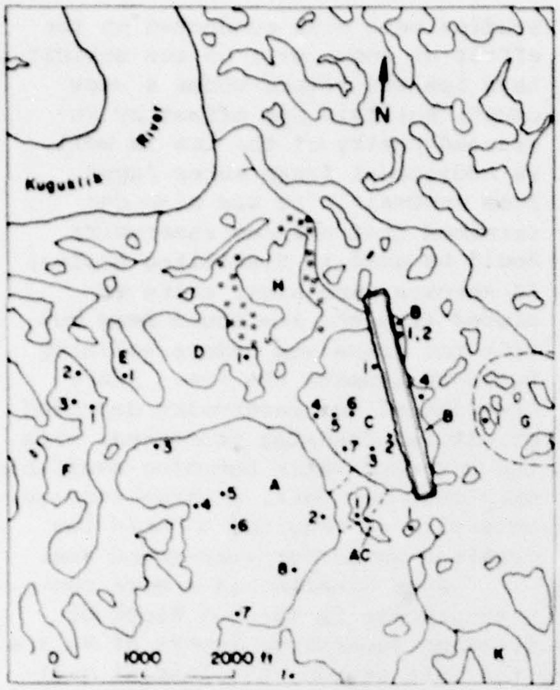


Figure 4. Sampling sites.

Sampling sites for the daily samples taken in 1977 are marked in Figure 4 and are listed and described in Appendix A. Sampling in 1978 primarily concentrated on Lake A, although periodic samples were taken at other lakes.

Water samples were obtained by lowering a plugged bottle to the desired depth (usually either near the surface or bottom) and then removing the plug. During the two extended sampling periods in 1977, the samples were analyzed for chloride concentrations by using an Orion 407A Specific Ion Meter with a combination chloride electrode. A Hach chloride test on the same sample was also performed. Samples taken in October 1977 and May-September 1978 were analyzed in the laboratory for chloride and other water quality parameters.

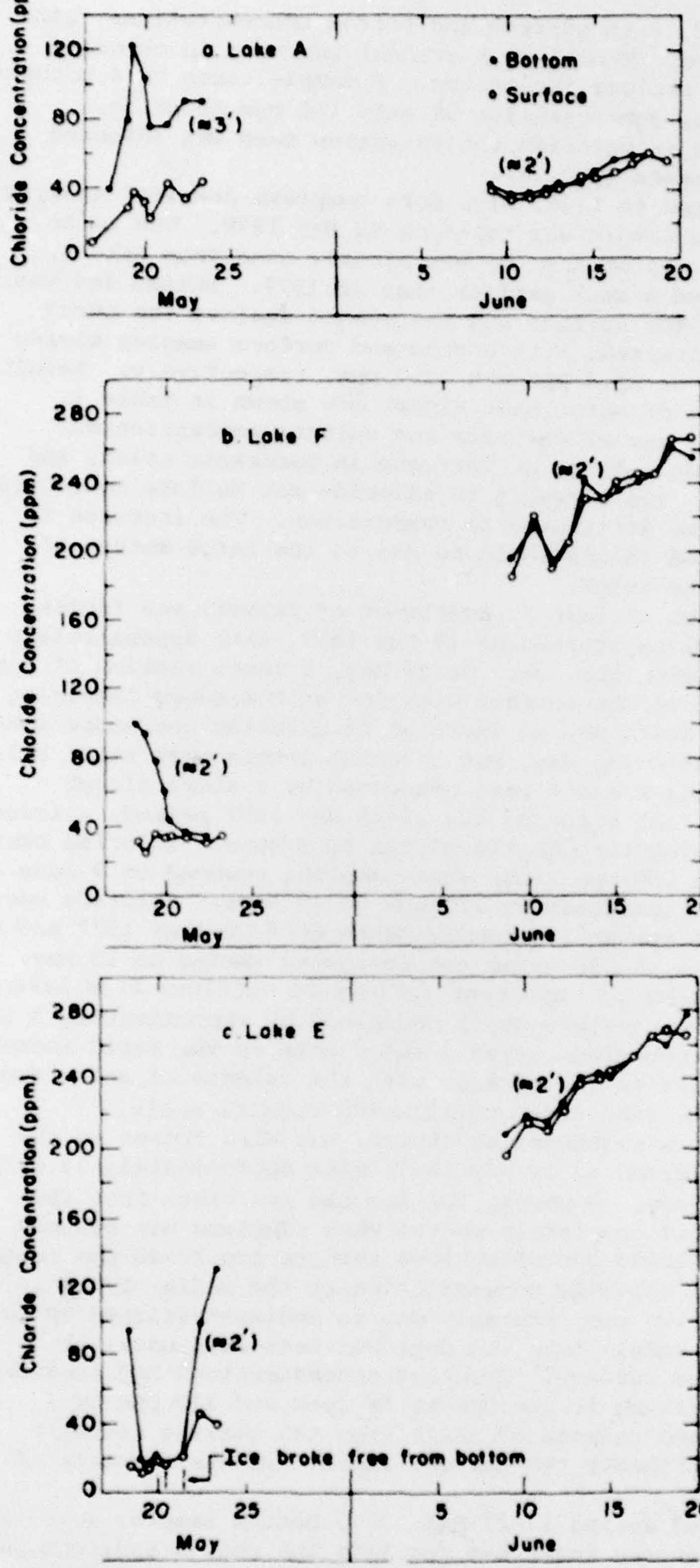
Tide data during 8-22 June 1977 were obtained by use of a graduated stake implanted in the Kuguklik River near Kipnuk. Relative heights were measured at various times. The maximum observed tidal range was 6.2 ft.

A visual ground reconnaissance was made of lakes A, E, F, and B for inlets and outlets, and the pattern was later observed from the air. Observations of drainage patterns of the lakes were noted on a map (Fig. B1).

Water Quality

Water quality within the lakes near Kipnuk was better than originally anticipated. The chloride concentration in lake A was within allowable limits through October 1977, shortly before freeze-up. Three major lakes were sampled. Since each was in a different stage of thawing during the initial sampling period of 17-25 May 1977, each will be discussed separately.

Lake A, the large lake to the south of Kipnuk, had a floating ice layer greater than 31.6 in. thick over most of its surface on 17 May 1977, with 13.4 in. of water beneath the ice. However, ice was still frozen to the bottom around the edges, with fresh water pools forming on top of the ice. Although not as far advanced, a similar melting pattern was observed at the other lakes sampled. The plot of chloride concentrations at Lake A (Fig. 5a) illustrated the difference in chloride concentrations for water beneath the ice cover and water at the surface for the period 17-23 May. By the time sampling was resumed on 9 June 1977, the ice still covered approximately 90% of the lake surface but was rotten and broken into large chunks, allowing mixing. Chloride concentrations indicated



a. Lake A, May-June 1977

b. Lake F, May-June 1977

c. Lake E, May-June 1977

Figure 5. Chloride concentrations in three thaw lakes near Kipnuk.

that mixing had occurred, with surface and bottom concentrations being in the 35 to 60 ppm range. There was a gradual increase in chloride concentration after all surface ice melted. A sample taken on 4 October 1977 indicated a chloride concentration of only 150 ppm chloride, which was a smaller rise in chloride concentration than was inferred from the villagers' comments (App. B).

Sampling was repeated in 1978, with more complete chemical analyses being done. The initial sample was taken on 12 May 1978. Due to an unusually warm spring, much of the ice was already gone from Lake A, although sampling started a week earlier than in 1977. Rotten ice was floating over 60-70% of the surface and was pushed against the north edge. The lake was well-mixed, with bottom and surface samples giving chloride concentrations of 23.4 ppm and 23.7 ppm, respectively. Results of the chemical analyses of water near Kipnuk are shown in Table 1. There was a gradual increase of chloride and sulfate concentrations throughout the summer, as well as an increase in hardness, color, and total dissolved solids. The increase in chloride and sulfate concentrations and hardness can be attributed to evaporation. The increase in color and total dissolved solids would be due to the large amount of organic material near the water.

The northern section of lake F, southwest of Kipnuk, was frozen to the bottom when sampling started on 17 May 1977, with approximately 13.4 in. of water overlying the ice. On 21 May, a large section of ice at the lake center rose to the surface with ice at the edges remaining frozen to the bottom. There was an increase in chloride concentrations in samples taken the following day, but chloride levels were still below 100 ppm (Fig. 5b). Lakes E and F were connected by a short slough running from lake E to lake F during the 17-23 May 1977 period, although water was no longer moving through the slough by 9 June. Chloride concentrations were in the 200-ppm range when sampling resumed on 9 June and gradually increased to approximately 270 ppm on 19 June. Chloride concentration was only 250 ppm in the sample taken on 4 October 1977 and was reduced to 91 ppm in the sample taken the following spring on 12 May. Since there were no longer any apparent inflows or outflows from lake F on 9-19 June 1977, and since lake depth decreased by approximately 3 in., it is believed that evaporation played a major role in the rapid increase of chloride concentration in the spring, with the release of salts from soil thawing beneath the lake also contributing significantly.

Lake E, a small lake southwest of Kipnuk, was also frozen to the bottom when sampling started on 17 May 1977, with approximately 13.0 in. of water overlying the ice. However, the ice had not risen from the bottom by 23 May, and had completely melted when sampling was resumed on 9 June. Initial chloride concentrations were in the 20-40 ppm range (Fig. 5c). The initial chloride concentration at the sediment/ice interface was approximately 100 ppm (probably due to sediment stirred up by the ice auger when the sample hole was dug) but decreased until it approximated that at the surface. Chloride concentrations had increased to 190 ppm by 9 June, rising to 260 ppm by 19 June and 330 ppm by 4 October. Evaporation and release of salts from the thawing sediment beneath the lake were probably the primary factors in the increase of chloride concentration.

In a test conducted during 17-23 May 1977, bottom samples were taken from several lakes after the auger had dug into the bottom sediment in an attempt to determine if significant amounts of salts were deposited beneath ice frozen to the bottom. Values for surface samples, the sediment/ice interface, and the sediment-water mix are shown in Table 2

Table 2. Chloride concentrations (ppm) of sediment-water mixture.

Lake	Surface	Sediment/ice interface	Sediment-water mix
A	7	13	124
E	33	40	135
F	17	16	81
G	10	12	182

for lakes A, E, F and G. There is a sharp rise in chloride concentrations once the bottom sediment is penetrated. It is hypothesized that the salts in the soil are released into the lake waters as the lake bottom thaws, thus increasing the salinity of the lakes. Much of the release of salts from the soil probably occurs shortly after ice melt, since this is the period which has the most rapid rate of increase of chloride concentration in lakes E and F.

Storage Areas

The village of Kipnuk has a population approaching 400, with a current water consumption rate of approximately 5 gallons per capita per day (gpcd). Using an estimate of 25 gpcd of water once a water supply is assured, water storage for 500,000 ft^3 would be necessary to provide a year-round water supply.

The lake B (trench) group (a small group of lakes near the airstrip) appears to be most practical for open-water storage, since these lakes already have some diking and are deep enough so that they would not freeze to the bottom during the winter. Cross sections and estimated volumes are shown in Figure 6. The lake with sample site B1 appears to have the greatest storage potential, due to its large volume (over 600,000 ft^3) and its continuous diking on three sides, with the airstrip forming the fourth side. The dikes and airstrip are in relatively good condition except for some erosion and undercutting along the banks. The dikes on three sides of lake B-1 are 6 to 8 ft lower than the airstrip. Villagers stated that fall storm tides have overtopped the dikes in the past but have not reached the level of the airstrip. Protection against storm tides, salinity intrusion and erosion could be accomplished by building up the dikes, and then lining the entire lake with flexible membrane. The estimated changes in water level chloride concentration on a monthly basis are illustrated in Figure 7. Calculations and assumptions are in Appendix A.

Lakes B3 and B4 also have large volumes and diking; however, the diking is in relatively poor condition, as evidenced by the drainage pattern shown going through them (Fig. B1). These two lakes are also more irregularly shaped than lake B-1, increasing the difficulty of lining them with membrane.

Any portion of lake B used for storage will have to be pumped out before fresh water is pumped into it, due to the high chloride concentrations shown in Figure 8. The extremely high concentrations at site B-4 indicate that salt water has intruded into the lake in the past.

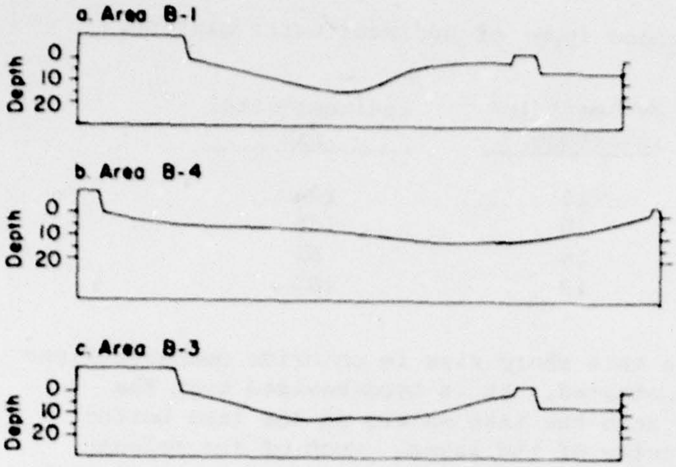


Figure 6. Cross sections of possible storage areas.

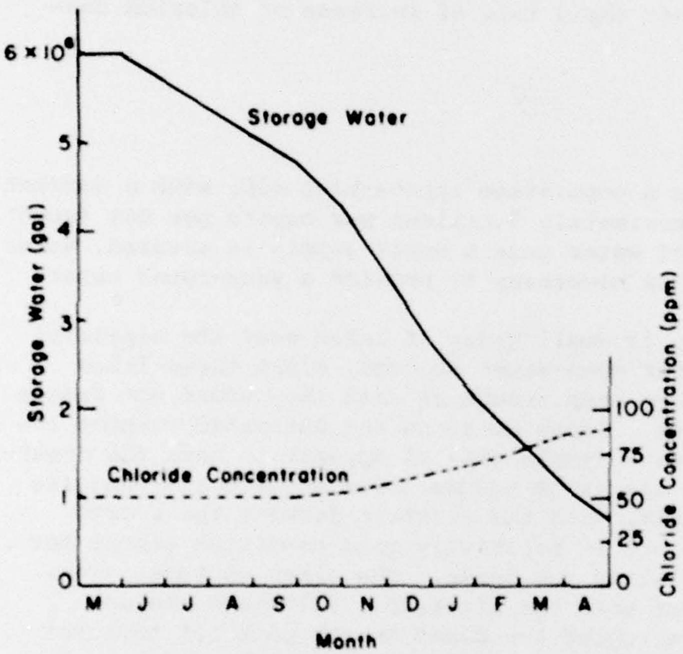


Figure 7. Estimated water volume and salinity changes in Kipnuk storage area.

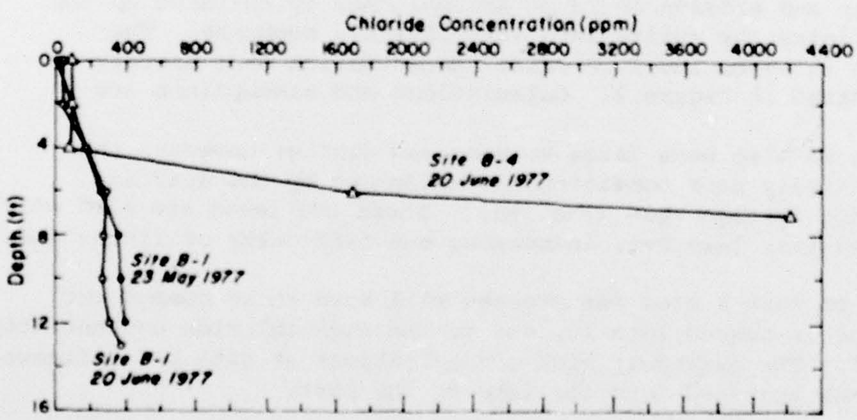


Figure 8. Salinity profile vs depth-Lake B.

Another method of storage would be surface storage tanks, installed with heating elements and mounted on wooden pads. There is sufficient solid land west of the village that a group of these tanks could be constructed near Kipnuk. Lakes A, E, and F are well within pumping range of this site. A central watering site could be supplied for the village in this manner.

Conclusions

The use of the shallow tundra lakes near Kipnuk as a seasonal fresh water source during the snowmelt season is a viable idea, and is in fact already being practiced by the villagers. Chloride concentrations are lowest during the snowmelt, as are color, turbidity, hardness, iron, and total dissolved solids. There is sufficient volume (over 15 million ft^3) in lake A alone to exceed the estimated annual water use by the village. There is also ample time, approximately 3-6 weeks, to pump water from the lakes to a storage area.

The use of the lakes as a seasonal water source appears feasible for Kipnuk. However, the effect of a storm tide on the salinity of the lakes is not known. The water may still be of sufficiently high quality to be collected in the spring after the storm tide, but the time available to collect it may be shorter.

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Appendix A. Test Data

Table A1. Monthly water volume and salinity for storage at Kipnuk, Alaska.

Month	Avg.[1] temp. °F	Freezing[2] °F days	Cum. freezing °F days	Total[3] ice thick. (in)	Incr. ice thick. (in)	Water[4] usage (1000 gal)	Water equi[5] of incr. ice (1000 gal)	Remaining[6] water (1000 gal)	Salinity[7] (ppm)
May	40.1	-	-	-	-	310	-	6000	50
Jun	51.6	-	-	-	-	300	-	5700	50
Jul	54.7	-	-	-	-	310	-	5390	50
Aug	52.3	-	-	-	-	310	-	5080	50
Sep	45.0	-	-	-	-	300	-	4780	50
Oct	30.2	56	56	4	4	310	204	4266	52
Nov	17.2	444	500	13	9	300	459	3507	57
Dec	4.4	856	1356	22	9	310	459	2738	63
Jan	5.1	834	2190	28	6	310	306	2122	69
Feb	8.2	666	2856	32	4	280	204	1638	76
Mar	11.4	639	3595	36	4	310	204	1124	85
Apr	24.5	225	3820	37	1	300	51	773	89

1 Average temperature from Bethel from NOAA records, 1941-1970
2 (32°-avg. temp.) X no. of days in month; 0 if avg. temp = 32°F
3 Using $Z = a\sqrt{s}$, where Z = ice thickness, inches
a = coefficient (0.6) for average lake with snow (Michel 1971, p. 79)
s = degree days of frost, °F -days
4 Assume daily water usage of 10,000 gal.
5 Water equiv. = (surface area) x (incr. ice thickness) x (ice density)
= (90,800 ft^2) x (incr. ice thickness) x (0.9)
6 Assume storage of 6,000,000 gal. at end of May, from pumping surrounding lakes
7 See Table A2 for calculations, assume 50 ppm as initial concentration

Table A2. Salinity Calculations.

Month	Water-equiv. of incr. ice (1000 gal)	Prev. month[1] chloride conc. (ppm)	Extruded chloride units	Sub-ice[2] Water (1000 gal)	Existing[3] chloride units	R[4]	Final[5] chloride conc. (ppm)
Oct	204	50	8,160	4,470	223,500	0.04	52
Nov	459	52	19,030	3,966	205,558	0.09	57
Dec	459	57	20,794	3,197	181,041	0.11	63
Jan	306	63	15,455	2.428	153,286	0.10	69
Feb	204	69	11,342	1,842	128,015	0.09	76
Mar	204	76	12,347	1,328	100,470	0.12	85
Apr	51	85	3,466	824	70,001	0.05	89

1 Assume 80% of salts in new ice are extruded during month.
Extruded chloride units = 0.8 (prev. month's chloride conc.) (Water equivalent of new ice)
2 Sub-ice water = (prev. month's remaining water) - (Monthly water usage)
3 Existing chloride units = (sub-ice water) x (prev. month's chloride conc.)
4 R= (extruded chloride units)/(existing chloride units)
5 Final chloride concentration = (1+R) x (prev. month's chloride conc.)

Appendix B: Villagers' Comments

Meeting with Village Council

A meeting was held with the Kipnuk Village Council on 18 May 1977 to obtain information on which lakes could supply fresh water during breakup, and to obtain ideas on when and how the lakes become brackish each year.

It was stated that the villagers do not use any waters adjacent to the village for their water supply for fear of contamination from village waste material. These areas were identified as lakes C, D, and H, and the cluster of lakes lettered M (see Fig. B1). However, it was later determined that the Bureau of Indian Affairs (BIA) school pumps snowmelt from lake C in order to replenish its water tanks. Lakes outside those mentioned above are generally acceptable for fresh water during the early spring. Suitable nearby lakes identified by the villagers included lakes A, E, F, G, and K. The villagers said the lakes stayed very fresh until the ice lifts off the bottom (the lakes freeze solid in the winter). After the ice lifts, they claimed that salinity increased due to mixing. The water from the lakes is used for drinking water into June, and at times is used throughout the summer for washing and laundering.

The council was questioned about the population of Kipnuk and the estimated water usage rate. Kipnuk has a population of approximately 400 people. The fresh water usage rate is greater in winter than in summer, since any fresh water obtained in winter must be used for both cleaning and drinking, while in summer the fresh water is used only for drinking, with lake water being used for cleaning purposes. The council president later told us that a family of five uses a 55-gallon drum of water in 2-3 days in the winter, for an estimated consumption rate of 5 gallons per capita day (gpcd).

The council was also questioned about storm tides inundating the area and increasing the salinity of the lakes. The villagers stated that storm tides are relatively rare, 1 or 2 per year, and usually occur in late fall when there is a combination of high tides and strong onshore winds. They would not appear to have any effect on the lakes during the snowmelt season. However, the principal of the BIA school later remarked that regular tidal action up the Kuguklik River increases the salinity of the lake waters. During the 8-22 June 78 period, normal tidal action was not observed to have any effect on chloride concentrations, although a storm tide could inundate lake B next to the runway.

General Information

Residents of Kipnuk were helpful in volunteering information about the Kipnuk area. When lake B was mentioned as a possible storage area, there were several comments made concerning its use in its current condition. Nearly all those who made comments were concerned with the amount of dirt blown into the lake by aircraft landing and taxiing on the airstrip, as well as dirt introduced by natural erosion by wind and rain. There was also concern expressed about pilots who occasionally use the lake as a latrine.

Lake B is connected by a slough to the Kuguklik River. Several persons stated that the fall storm tides enter lake B, adding salt water to it. The BIA school had pumped water from lake B one fall and found it to leave a "sticky" residue when used for bathing, etc.

Another item discussed was the use of fresh water streams located at Tern Mountain, to the north-northwest of the village. This is currently the only fresh water source for the villagers during the dry summer periods. A 55-gallon drum must be taken by boat down the Kuguklik River, north along the shore of Etolin Strait, then upstream on an unidentified river to a "lagoon" with many small fresh water streams emptying into it—a one-way trip of approximately 30 miles. The springs were said to flow throughout the entire year. For the villagers, the trip is long, costly, and can be made only at high tide. Therefore, water from these springs, even though considered the best in the area, is seldom used. Samples taken from the lagoon, about ¼ mile below the springs, contained concentrations of 75 ppm and 82 ppm of chloride at depths of 0 and 2 ft, respectively. An interesting feature at the lagoon was a definite line of debris about 8 ft above the observed high tide level, presumably deposited by storm tides of previous years.

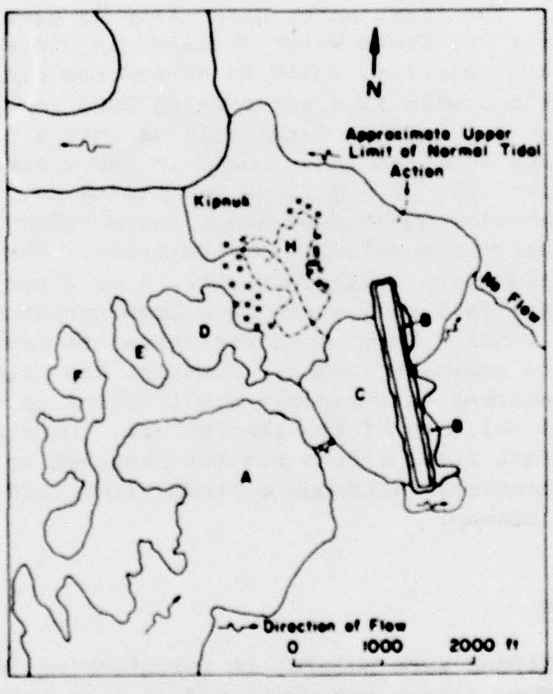

Figure B1. Flow pattern through lakes.