Fishery Data Series No. 95-26

Evaluation of the Thermal Habitat Volume for Lake Trout in Selected Lakes of Southwest Alaska, 1994

by

Daniel Bosch,

Lewis Coggins,

and

R. Eric Minard

November 1995

Alaska Department of Fish and Game

Division of Sport Fish

Symbols and Abbreviations

The following symbols and abbreviations, and others approved for the Système International d'Unités (SI), are used in Division of Sport Fish Fishery Manuscripts, Fishery Data Series Reports, Fishery Management Reports, and Special Publications without definition. All others must be defined in the text at first mention, as well as in the titles or footnotes of tables and in figures or figure captions.

Weights and measures (metric)

centimeter	cm
deciliter	dL
gram	g
hectare	ha
kilogram	kg
kilometer	km
liter	L
meter	m
metric ton	mt
milliliter	ml
millimeter	mm

Weights and measures (English)

cubic feet per second	ft^3/s
foot	ft
gallon	gal
inch	in
mile	mi
ounce	oz
pound	lb
quart	qt
yard	yd

Spell out acre and ton.

Time and temperature

day	d
degrees Celsius	°C
degrees Fahrenheit	°F
hour (spell out for 24-hour clock)	h
minute	min
second	s

Spell out year, month, and week.

Physics and chemistry

all atomic symbols	
alternating current	AC
ampere	A
calorie	cal
direct current	DC
hertz	Hz
horsepower	hp
hydrogen ion activity	pH
parts per million	ppm
parts per thousand	ppt, ‰
volts	V
watts	W

General

All commonly accepted abbreviations.	e.g., Mr., Mrs., a.m., p.m., etc.
All commonly accepted professional titles.	e.g., Dr., Ph.D., R.N., etc.
and	&
at	@
Compass directions:	
east	E
north	N
south	S
west	W
Copyright	©
Corporate suffixes:	
Company	Co.
Corporation	Corp.
Incorporated	Inc.
Limited	Ltd.
et alii (and other people)	et al.
et cetera (and so forth)	etc.
exempli gratia (for example)	e.g.,
id est (that is)	i.e.,
latitude or longitude	lat. or long.
monetary symbols (U.S.)	$, ¢
months (tables and figures): first three letters	Jan,...,Dec
number (before a number)	# (e.g., #10)
pounds (after a number)	# (e.g., 10#)
registered trademark	®
trademark	™
United States (adjective)	U.S.
United States of America (noun)	USA
U.S. state and District of Columbia abbreviations	use two-letter abbreviations (e.g., AK, DC)

Mathematics, statistics, fisheries

alternate hypothesis	H_A
base of natural logarithm	e
catch per unit effort	CPUE
coefficient of variation	CV
common test statistics	F, t, χ^2, etc.
confidence interval	C.I.
correlation coefficient	R (multiple)
correlation coefficient	r (simple)
covariance	cov
degree (angular or temperature)	°
degrees of freedom	df
divided by	÷ or / (in equations)
equals	=
expected value	E
fork length	FL
greater than	>
greater than or equal to	≥
harvest per unit effort	HPUE
less than	<
less than or equal to	≤
logarithm (natural)	ln
logarithm (base 10)	log
logarithm (specify base)	log_2, etc.
mideye-to-fork	MEF
minute (angular)	'
multiplied by	x
not significant	NS
null hypothesis	H_O
percent	%
probability	P
probability of a type I error (rejection of the null hypothesis when true)	α
probability of a type II error (acceptance of the null hypothesis when false)	β
second (angular)	"
standard deviation	SD
standard error	SE
standard length	SL
total length	TL
variance	Var

FISHERY DATA SERIES NO. 95-26

EVALUATION OF THE THERMAL HABITAT VOLUME FOR LAKE TROUT IN SELECTED LAKES OF SOUTHWEST ALASKA, 1994

by

Daniel Bosch,
Division of Sport Fish, Anchorage
Lewis Coggins
and
R. Eric Minard
Division of Sport Fish, Dillingham

Alaska Department of Fish and Game
Division of Sport Fish, Research and Technical Services
333 Raspberry Road, Anchorage, Alaska, 99518-1599

November 1995

This investigation was partially financed by the Federal Aid in Sport Fish Restoration Act (16 U.S.C. 777-777K) under project F-10-10, Job No. R-2-9.

The Fishery Data Series was established in 1987 for the publication of technically-oriented results for a single project or group of closely related projects. Fishery Data Series reports are intended for fishery and other technical professionals. Distribution is to state and local publication distribution centers, libraries and individuals and, on request, to other libraries, agencies, and individuals. This publication has undergone editorial and peer review.

Daniel Bosch,
Alaska Department of Fish and Game, Division of Sport Fish,
333 Raspberry Road, Anchorage, AK 99518-1599, USA,
Lewis Coggins and R. Eric Minard,
Alaska Department of Fish and Game, Division of Sport Fish
P.O. Box 230, Dillingham, AK 99737-0605, USA

This document should be cited as:
Bosch, Daniel, Lewis Coggins, and R. Eric Minard. 1995. Evaluation of the thermal habitat volume for lake trout in selected lakes of Southwest Alaska, 1994. Alaska Department of Fish and Game, Fishery Data Series No. 95-26, Anchorage.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

ABSTRACT

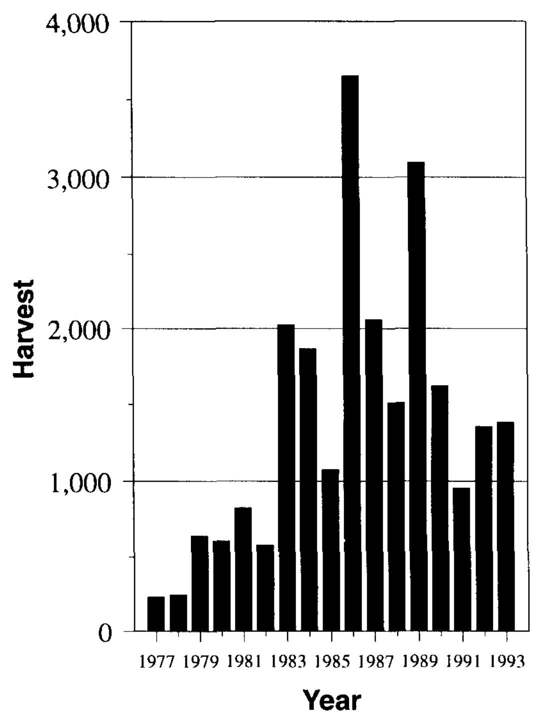
This was the first year of a multiyear study to evaluate thermal habitat volume and sustained yield for lake trout *Salvelinus namaycush* in 14 lakes in Southwest Alaska (Brooks, Naknek, Lower Ugashik, Tikchik, Kontrashibuna, Lower Twin, Upper Twin, Turquoise, Telaquana, Goodnews, Heart, Kagati, and Kanuktik lakes, and Lake Clark). During 1994 bathymetric profiles were taken at study lakes where no bathymetric maps existed. Temperature profiles were also collected from all 14 study lakes. The thermal habitat volume (THV) for lake trout is the volume of water found between 12°C and 8°C. In previous studies a strong relationship has been found between the July THV and the sustained yield of lake trout. THVs resulted in estimates of sustained yield of lake trout ranging from 1.1 kg/ha/yr in Naknek Lake and Tikchik Lake to 4.8 kg/ha/yr in Kanuktik Lake. On average, the THVs from Southwest Alaska lakes are higher than the THVs found for similar sized lakes in Ontario, Canada, and Southcentral Alaska. The Southwest Alaska lakes currently receive little or no fishing pressure, so the accuracy of the sustained yield estimates could not be substantiated through historic harvest records. Recommendations were made to reduce the study to only those lakes with reliable harvest information based on the Statewide Harvest Surveys.

Key words: Lake trout, *Salvelinus namaycush*, thermal habitat volume, Southwest Alaska, sustained yield.

INTRODUCTION

Harvests of lake trout *Salvelinus namaycush* by recreational fisheries in the Southwestern Alaska Sport Fish Management Area (Figure 1) remained below 1,000 fish annually from 1977 to 1982 (Mills 1979-1983). Since 1983, the harvest of lake trout has ranged from 1,000 to 3,600 fish annually (Mills 1984-1994). Current harvests are not considered excessive; however, growing interest in the recreational fisheries of Southwest Alaska has prompted resource managers to consider the effects of increased sport harvests. Presently, sport bag limits for lake trout are considered liberal: 4 per day and in possession with no size limit (ADF&G 1994). Little biological information concerning the harvest is available.

Lake trout is a slow growing, late maturing, long-lived species that is easily over-harvested (Burr 1987, Szarzi 1993). The growth of lake trout is generally slow and not clearly related to latitude (Scott and Crossman 1973). In Alaska, age at complete maturity ranges from 7 to 20 years and is related to latitude; fish mature later in life the farther north they reside (Burr 1987). Lake trout are also long-lived and can reach more than 50 years of age (Burr 1987). In Southcentral Alaska Szarzi (1993) found female lake trout did not generally spawn every year, while male lake trout generally do. Fecundity of lake trout is size related, and ranges from 400 to 1,200 eggs per 453 kilograms weight of the female (Scott and Crossman 1973). A broad range of age classes and good recruitment into the population is needed to prevent over-exploitation or to help populations rebound from overexploitation (Szarzi 1993).



From: Minard and Dunaway (1994)

Figure 1.-Historical harvest of lake trout from the Southwestern Alaska Sport Fish Management Area.

Christie and Regier (1988) found a relationship between the summer temperature regime of a lake and the production of lake trout. In a study of 15 large lakes in Canada, they were able to explain 86% of the variability in lake trout harvests by using 10-day averages of the volume of water between 8°C and 12°C. Payne et al. (1990) developed a model relating thermal habitat volume (THV: defined for lake trout as the volume of water between 8°C and 12°C) measured in July and the harvest of lake trout. The lakes in the Payne et al. (1990) study all had years of harvest data (determined to be sustainable), were >100 ha, had fairly stable temperature regimes, and moderate to high fishing pressure. The model of Payne et al. (1990) estimates a maximum sustainable yield (MSY) of lake trout from a study lake with the above characteristics. Payne et al. (1990) considered this estimate to be the *potential* MSY for each study lake.

Lake trout habitat in the lakes of Southwestern Alaska may be similar to that studied in Canada. Szarzi (1993) found that for Paxson Lake in the Copper River drainage, and Lake Louise and Susitna Lake in the Susitna River drainage of Southcentral Alaska, the THV model provided estimates of MSY for lake trout similar to other models. Application of the THV model to lakes in Southwest Alaska will allow estimation of MSY for selected lakes known to hold lake trout. Although the Division of Sport Fish does not emphasize management for maximum sustained yield of resident species, comparison of MSY estimates with current levels of yield allows managers to evaluate the current levels of harvest.

The specific objectives in 1994 were:

1. Measure the thermal habitat volume, used to estimate the maximum sustainable yield, for lake trout in selected lakes in Southwest Alaska.
2. Estimate the mean weight of the sport harvest of lake trout from lakes measured for THV.

METHODS

Site Descriptions

All lakes in this study are in a National Park, National Wildlife Refuge, or State Park (Figure 2). Naknek and Brooks lakes are located within Katmai National Park and Preserve. Lower Ugashik Lake is in the Alaska Peninsula National Wildlife Refuge. Lake Clark National Park and Preserve contains Lake Clark, Kontrashibuna, Lower Twin, Upper Twin, Turquoise, and Telaquana lakes. Goodnews, Kanuktik, Kagati, and Heart lakes are all in the Togiak National Wildlife Refuge. Finally, Tikchik Lake is within the Wood-Tikchik State Park. These lakes are all remote and accessible by airplane only (Table 1). Selection of lakes to be sampled was completed considering the sport harvest of lake trout and geographic distribution of representative lakes throughout the area.

Estimation of Thermal Habitat Volume

The thermal habitat volume (THV) for lake trout is defined as the volume of lake water within the temperature range 8°-12°C during the period of maximum thermal stability which generally occurs in July or August (Payne et al. 1990). To estimate THV, both the depth and temperature profiles of the lake must be measured. Of the 14 Southwestern Alaska lakes for which THV was estimated during 1994, bathymetric charts were available for 11 of the lakes. The remaining three: Lower Ugashik, Turquoise, and Telaquana lakes, were sampled for bathymetric data in 1994 (Table 2). Temperature profiles were established from two sampling trips to each of the 14 lakes. (Table 2).

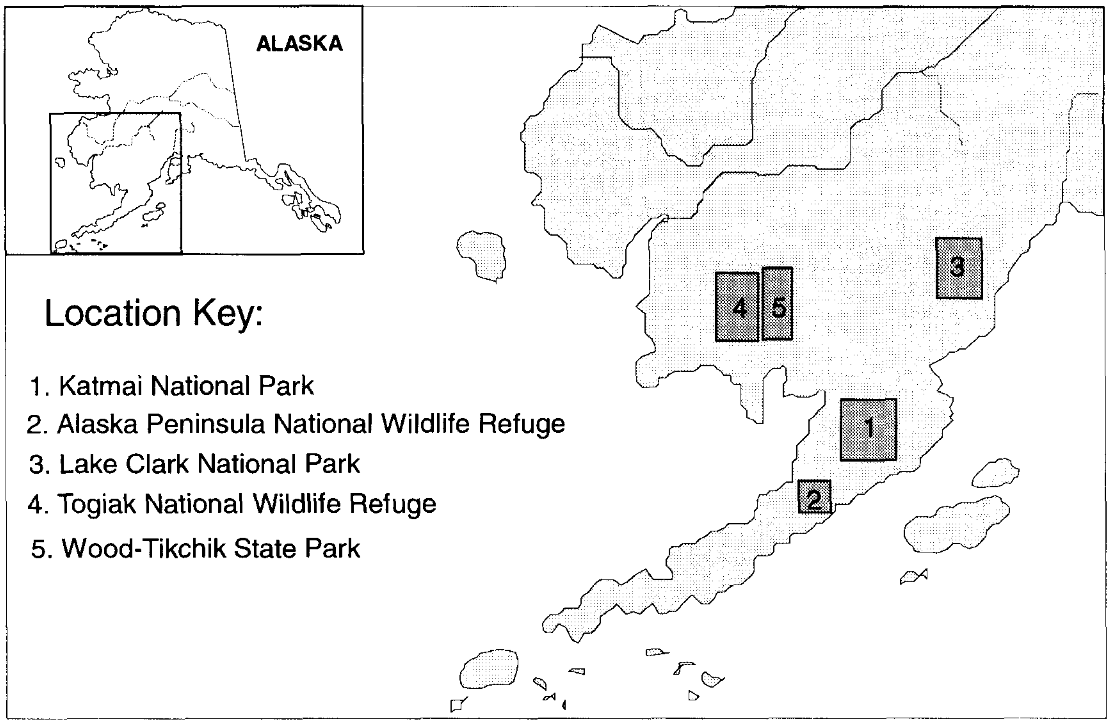


Figure 2.-Locations of parks and refuges containing study lakes.

Table 1.-Study lakes and USGS quadrangles where they are located.

Site	Latitude	Longitude	Quadrangle
Naknek Lake	58° 39' N	155° 52' W	Mt. Katmai
Brooks Lake	58° 30' N	155° 44' W	Mt Katmai
Lower Ugashik Lake	57° 41' N	156° 39' W	Ugashik
Tikchik Lake	59° 59' N	158° 30' W	Dillingham
Lake Clark	60° 15' N	154° 00' W	Lake Clark
Kontrashibuna Lake	60° 12' N	154° 00' W	Lake Clark
Lower Twin Lake	60° 38' N	153° 35' W	Lake Clark
Upper Twin Lake	60° 38' N	153° 35' W	Lake Clark
Turquoise Lake	60° 47' N	152° 57' W	Kenai
Telaquana Lake	60° 57' N	152° 52' W	Lake Clark
Goodnews Lake	59° 28' N	160° 31' W	Goodnews Bay
Heart Lake	60° 07' N	159° 38' W	Bethel
Kagati Lake	59° 52' N	160° 05' W	Goodnews Bay
Kanuktik Lake	59° 44' N	160° 19' W	Goodnews Bay

Table 2.-Dates of temperature and bathymetric sampling of the 14 study lakes in 1994.

Site	Temperature Sampling Event 1	Temperature Sampling Event 2	Bathymetric Sampling
Brooks Lake	23 July	24 August	
Naknek Lake	30-31 July	24 August	
Lower Ugashik Lake	11 August	29 August	9-13 July
Tikchik Lake	6 August	20 August	
Lake Clark	5 August	17 August	
Kontrashibuna Lake	5 August	18 August	
Lower Twin Lake	4 August	16 August	
Upper Twin Lake	4 August	16 August	
Turquoise Lake	5 August	17 August	2 July
Telaquana Lake	5 August	16 August	29-30 June, 1 July
Goodnews Lake	18 July	16 August	
Heart Lake	18 July	16 August	
Kagati Lake	18 July	23 August	
Kanuktik Lake	18 July	8 September	

Bathymetric Data Collection

A three-step process was used to gather and summarize bathymetric data for Lower Ugashik, Turquoise, and Telaquana lakes: (1) identify transects on a high quality map of the lake; (2) measure depths along those transects; and (3) transcribe the depth profile of each transect onto the map of the lake. As guidelines for selecting transect locations, the major axis (i.e., length; the longest straight line distance from one shore to the opposite shore) and the minor axis (i.e., width; the longest straight line to opposite shores that is perpendicular to the major axis) were identified and drawn on each map. At least three transects parallel to the length of the lake were drawn: the major axis and one transect on each side of the major axis, parallel to the major axis, and intersecting the minor axis half the distance between the shore and the point where the major and minor axes intersected. Likewise, at least three transects were drawn parallel to the width of the lake: the minor axis and one transect on either side of the minor axis, parallel to the minor axis, and intersecting the major axis half the distance between the shore and the point where the major and minor axes intersected. Also, at least three transects were drawn from islands to recognizable land marks on shore. The depth along each transect was measured by skiff with a Lowrance model Eagle Mach I chart recording fathometer[1]. A Trimble model Scout global positioning system (GPS) unit[1] was used to identify the transect end points and to navigate along the transects. The speed of the skiff was held constant to ensure that the length of the fathometer trace was proportional to the distance that the skiff traveled along the transect. Fathometer traces

[1] Use of brand names does not constitute endorsement

were inspected and the distance to each 2.5 meter change in depth recorded on these printouts. The ratio between the map transect lengths and the fathometer trace lengths were calculated and used to transcribe lake depth in 2.5 meter intervals on the map transects.

The depth profile of each lake was converted to a set of three-dimensional points describing the lake bottom using a Summasketch III Professional digitizing tablet and program Digitize by Rockware Inc.[2] A reference point was identified on each map as the origin of an X-Y coordinate system. The X and Y dimensions were calculated from a set of reference points supplied to the program and scaled in meters. The Z dimension was entered for each X-Y pair and scaled in negative meters from the lake surface. For Lower Ugashik, Turquoise, and Telaquana lakes, this was accomplished by digitizing the depths along the transects and the lake boundaries. For the remaining 11 lakes, the contour lines and lake boundaries were digitized from existing maps. The data points were then supplied to program Surfer by Golden Software Inc.[2] to extrapolate a surface that defined the lake bottom. Surfer was then used to conduct volume and area calculations as well as to draw bathymetric maps of the lakes. Bathymetric maps of each study lake are found in Appendix A.

Temperature Data Collection

Measurements of water temperature were taken at three locations on each lake. One sample of temperature was taken in July or early August and the second sample in August (Table 2). The same three locations, defined by GPS coordinates, were used for both sampling excursions. These locations were in the deepest parts of the lake and were separated by at least 1 kilometer. Measurements were made at 2.5 meter intervals using a Grant/YSI model 3800[1] from the surface to a depth of at least 50 meters or until the lake bottom was encountered. The mean temperature and its coefficient of variation at each 2.5 meter depth were estimated for each sampling event.

[2] Use of brand names does not constitute endorsement.

Thermal Habitat Volume

The depth of the lake between 8°C and 12°C was used to determine thermal habitat volume in two ways. The first approach is (Payne et al. 1990):

$$\mathrm{THV} = \frac{(D_2 - D_1)\left(A_1 + A_2 + \sqrt{A_1 A_2}\right)}{300} \qquad (1)$$

where:

D_2 = deepest depth that the average temperature is 8°C,

D_1 = shallowest depth that the average temperature is 12°C,

A_2 = cross-sectional area of the lake at D_2, and

A_1 = cross-sectional area of the lake at D_1.

The second method used Surfer to calculate the volume between the two depths. The THV was equal to the volume below the depth at 12°C minus the volume below the depth at 8°C. The minimum THV between each temperature sampling event was chosen as the THV for lake trout in each of the study lakes.

Biological Information

The weight of at least 28 sport harvested lake trout from each lake must be taken to the nearest 10 grams to meet objective 2 (Cochran 1977). This information was the most challenging to gather because sport fishing effort for lake trout is so diffuse in Southwest Alaska. We attempted to obtain weight information from three sources. First, commercial sport fishing guides were solicited to help. Interested guides were given equipment, training, and materials needed to collect weight and length data. This was planned to provide samples from a wide geographic area. Second, field crews from the Alaska Department of Fish and Game, National Park Service, and U. S. Fish and Wildlife Service collected weight data from anglers on an opportunistic basis. Third, a historical lake trout database was examined for hook and line caught lake trout that had been weighed from the target lakes.

POTENTIAL HARVEST AND SUSTAINED YIELD

Thermal habitat volume was used as a predictor variable to estimate potential harvest of each lake according to (Payne et al. 1990):

$$\log_{10}(MSY) = 2.15 + 0.714\log_{10}(THV) \qquad (2)$$

where:

MSY = potential harvest (kg yr^{-1}), and

THV = thermal habitat volume in cubic hectometers (hm^3).

Potential sustained yield (kg ha^{-1} yr^{-1}) was then calculated as:

$$SY = \frac{MSY}{A} \qquad (3)$$

where:

SY = potential sustained yield (kg ha^{-1} yr^{-1}),

MSY = potential harvest (kg yr^{-1}), and

A = surface area of the lake (ha).

The sustained yield can be converted to numbers of lake trout by dividing MSY by the mean weight of lake trout sampled at the lake.

ACTUAL HARVEST WEIGHT

The actual harvest of lake trout from each lake in kg/yr was estimated by:

$$\hat{Y} = \hat{H}\overline{w}, \qquad (4)$$

and its variance by (Goodman 1960):

$$\hat{Var}(\hat{Y}) = \left[\hat{H}^2\hat{Var}(\overline{w})\right] + \left[\overline{w}^2\hat{Var}(\hat{H})\right] - \left[\hat{Var}(\overline{w}_t)\hat{Var}(\hat{H})\right] \qquad (5)$$

where:

$\hat{H}$ = sport harvest of lake trout from the lake estimated by the Statewide Harvest Survey, and

$\overline{w}$ = mean weight of lake trout sampled at the lake.

RESULTS

WEIGHT AND LENGTH INFORMATION

Sample size requirements (n = 28) were met at only four study sites: Kontrashibuna Lake, Lake Clark, Tikchik Lake, and Naknek Lake (Table 3). Nineteen harvested lake trout were weighed at Lower Twin Lake. This is a marginal sample size, however it was used to estimate potential yield because it probably is still a fairly representative sample from that lake. Because sample size requirements were not met at the other study lakes, the average weight of lake trout from Naknek Lake was substituted to estimate yield of these lakes. Lake trout from Naknek Lake were the largest fish of any of the study sites. This would provided conservative estimates of yield for these other sites. Weight information from sites with small sample sizes can be found in Appendix B.

Lake trout harvested from Kontrashibuna Lake had a mean fork length of 441 mm and a mean weight of 867 g (Table 3). This lake provided the largest sample size of lengths and weights, even though it does not regularly appear in the Statewide Harvest Survey (Mills 1979-1994). These data were collected on 6 July, 8 August, and 30 August 1994. Lake trout measured from Lake Clark had a mean fork length of 533 mm and averaged 1,909 g. Forty-five lake trout were measured during five sampling events (by either fishing guides,

Table 3.-Biological information collected during 1994, from lakes where adequate sample sizes were collected.

	Lower Twin Lake	Kontrashibuna Lake	Lake Clark	Tikchik Lake	Naknek Lake
Length (mm)					
Sample Size	19	58	45	53	34
Mean	401	441	533	536	556
Mode	410	508	610	470	570
Standard Deviation	25	74	117	50	41
95% Upper Confidence Interval	413	460	568	550	570
95% Lower Confidence Interval	389	421	498	522	542
Maximum	440	610	820	648	650
Minimum	352	279	360	440	485
Weight (g)					
Sample Size	19	58	45	53	34
Mean	788	867	1,909	1,763	2,051
Mode	700	455	800	1,800	2,000
Standard Deviation	164	374	1,063	465	490
95% Upper Confidence Interval	867	965	2,229	1,890	2,223
95% Lower Confidence Interval	709	769	1,589	1,635	1,880
Maximum	1,200	2,270	5,200	2,900	3,200
Minimum	550	340	700	1,100	1,250

National Park Service, or ADF&G personnel). These sampling events took place during 3 June, 8 June, 12 June, 15 June, and 9 July 1994. Nineteen lake trout from Lower Twin lake had a mean fork length of 401 mm and a mean weight of 788 g. Data on these fish were collected on 28 June, 4 August, and 30 August 1994.

Thirty-four lake trout from Naknek Lake had a mean fork length of 556 mm and a mean weight of 2,051 g. These lake trout had the largest average weight from any of the five study lakes with adequate weight samples. Naknek Lake is also the largest lake and has the largest THV (Table 4) in the study. These biological data were collected during four sampling events: 17 June, 30 June, 1 July, and 15 July 1994. An adequate sample size was also obtained from Tikchik Lake in Wood-Tikchik State Park. Fifty-three lake trout had a mean fork length of 536 mm and a mean weight of 1,763 g. Most of these data were collected from 24 July to 31 July, while the last eight samples were taken during several days in the first half of August.

Table 4.-Minimum thermal habitat volumes (THV) and potential harvest and sustained yield for lake trout from Southwest Alaska study lakes, 1994.

Site	Surface Area (ha)	THV (hm^3)[a,b]	Potential Harvest (kg/yr)	Potential Sustained Yield (kg/ha/yr)	Mean Weight (kg)	Potential Sustained Yield (fish)
Brooks Lake[c]	5,480	601	13,624	2.5	2.051	6,680
Naknek Lake	56,321	4,917	61,072	1.1	2.051	30,206
Lower Ugashik Lake[c]	17,693	4,755	59,630	3.4	2.051	29,330
Tikchik Lake	5,892	215	6,527	1.1	1.763	3,676
Lake Clark	30,659	3,163	44,569	1.5	1.909	24,090
Kontrashibuna Lake	2,345	356	9,362	4.0	0.867	10,819
Lower Twin Lake	831	93	3,603	4.3	0.789	4,529
Upper Twin Lake[c]	1,503	178	5,717	3.8	2.051	2,785
Turquoise Lake[c]	1,300	74	3,063	2.4	2.051	1,521
Telaquana Lake[c]	4,632	604	13,661	2.9	2.051	6,549
Goodnews Lake[c]	382	22	1,296	3.4	2.051	633
Heart Lake[c]	565	24	1,360	2.4	2.051	661
Kagati Lake[c]	1,057	148	5,004	4.7	2.051	2,422
Kanuktik Lake[c]	807	103	3,873	4.8	2.051	1,889

[a] THVs were estimated during two sampling events (early and late). The minimum value from these two events was used here.

[b] hm^3 = cubic hectometers.

[c] Too few weight samples were obtained from this lake to estimate mean weight. The mean weight of lake trout from Naknek Lake (the largest mean weight available) was used to estimate sustained yield (fish) for this lake. This probably results in a conservative estimate of sustained yield.

Thermal Habitat Volume (THV) and Yield Estimates

Thermal habitat volume for lake trout was estimated for each study lake for both early and late temperature profiles (Appendix C). The minimum value was then used to estimate potential harvest (kg/yr) and potential sustained yield (in both kg/ha/year and in number of fish: Table 4). Using the minimum value provided conservative estimates of both THV and MSY. THV ranged from 22 cubic hectometers (hm^3) for Goodnews Lake (surface area 382 ha) to 4,917 hm^3 for Naknek Lake (surface area 56,321 ha). The potential sustained yield estimates corresponding to these estimates of THV (Table 4) vary from 1.1 kg/ha/yr or 30,206 fish for Naknek Lake to 4.8 kg/ha/yr or 1,889 fish for Kanuktik Lake. The largest potential harvest is once again from the largest lake, Naknek Lake, at 61,072 kg/yr. Ugashik Lake, a much smaller lake, follows closely with a harvest estimate of 59,630 kg/yr. The smallest estimate of harvest is for Goodnews Lake, the smallest lake, at 1,296 kg/yr.

The historic sampling and harvest information for lake trout that was available provided no usable weight information. A great majority of the lake trout in the archives were captured using gillnets. Historical hook and line data were available from Goodnews Lake (Appendix B2), but was not used because the sample size was small and the data old.

Current Harvest

Average annual harvest of lake trout from each study lake during the past 5 years and the past 10 years varied from 0 to approximately 300 (Table 5). Lakes with a low 5-year or 10-year average harvest also have few respondents to the statewide harvest survey (less than five a year most likely) and these may *not* have accurate estimates of lake trout harvest. Table 5 shows the average number of respondents for each of the study lakes. The

Table 5.-Average number of respondents (households) to the Statewide Harvest Survey who reported fishing at the study lakes during 1984-1993, and average estimated harvest of lake trout from the Statewide Harvest Survey during that period.

	10 Year Average (1984-1993)		5 year Average (1989-1993)	
Site	Respondents[a]	Harvest	Respondents[a]	Harvest
Brooks Lake	16	55	25	58
Naknek Lake	71	213	95	84
Lower Ugashik Lake	16	44	21	34
Tikchik Lake	22	167	32	184
Lake Clark	29	318	42	293
Kontrashibuna Lake	<1	2	1	4
Lower Twin Lake	0	0	0	0
Upper Twin Lake	0	0	0	0
Turquoise Lake	1	5	<1	0
Telaquana Lake	1	22	2	44
Goodnews Lake	<1	4	<1	7
Heart Lake	<1	4	<1	8
Kagati Lake	<1	37	1	66
Kanuktik Lake	<1	2	0	3

[a] <1 indicates at least some response (although the average is less than 1), while 0 indicates no respondents.

harvest of lake trout from lakes with fewer than 12 respondents is not considered reliable (Mills and Howe 1992). The harvest of lake trout from Naknek Lake includes Naknek Lake, Bay of Isles, Iliuk Arm, Brooks River, and Naknek River. The harvest of lake trout from the two rivers takes place very close to Naknek Lake and these fish are considered part of the Naknek lake trout stock.

DISCUSSION

Current recreational harvest levels appear fairly minimal and should not affect the lake trout abundance or production at any of the study lakes. The current daily bag limit of four lake trout also does not appear excessive. However, due to the remote nature of these lakes and the infrequent reports of harvest for some of these lakes, the estimates of lake trout harvest from the Statewide Harvest Survey may be biased.

All the estimates of yield (and THV) from Southcentral Alaska lakes (Szarzi 1993) are below yield estimates from Southwest Alaska lakes. At Paxson Lake estimates of yield from 1991 and 1992 were very similar (0.99 kg/ha and 1.03 kg/ha, respectively). At Lake Louise, however, yield estimates were 0.37 kg/ha/yr in 1991 and 1.21 kg/ha/yr in 1992. This indicates that THV estimates are not always stable from year to year. The yield estimate for Lake Susitna is 0.52 kg/ha/yr. These estimates of yield are generally below the yield estimates for lakes in this study (Table 4). Naknek and Tikchik lakes have the smallest estimates of yield from Southwest Alaska study lakes at 1.1 kg/ha/yr. Yield estimates for Southwest Alaska lakes range from this low, to a high of 4.8 kg/ha/yr for Kanuktik Lake.

The estimates of yield (and THV) from Ontario lakes can also be compared to lakes in Southwest Alaska. Payne et al. (1990) estimated the yield of 20 lakes in Ontario, Canada. Most of these lakes were quite larger than the lakes in this study. Payne et al. (1990) found that the estimated yield ranged from 0.02 kg/ha/yr to 3.0 kg/ha/yr. A trend also appeared in that larger lakes had smaller estimates of yield and smaller lakes had greater estimates of yield (kg/ha/yr). Most of the lakes in the Ontario study had an estimated yield considerably smaller than the lakes in Southwest Alaska. Comparison of lakes of the same relative size (surface area) shows Naknek Lake had an estimated yield of 1.1 kg/ha/yr while Amisk Lake in Ontario had an estimated yield of less than half that at 0.42 kg/ha/yr. The yield estimate of 2.9 kg/ha/yr at Telaquana Lake in Southwestern Alaska was nearly four times that of Lake Opeongo (0.68 kg/ha/yr) in Ontario. Only Bone Lake in Ontario was similar to a lake of its size in Southwest Alaska. Bone Lake had an estimated yield of 3.00 kg/ha/yr while Goodnews Lake had an estimate of 3.4 kg/ha/yr.

There are several reasons why THV for lakes in Southwest Alaska are, on average, considerably higher than those from Southcentral Alaska and Ontario. The study lakes in Southwest Alaska during the summer of 1994 did not appear to stratify like Ontario or Southcentral Alaska study lakes. A temperature profile from 8°-12°C could be found, but at times 12°C started at the lake surface. The yields for Southwest Alaska study lakes were generally larger than Ontario and Southcentral Alaska lakes because of the large THV to surface area ratio for Southwest Alaska Lakes. While an 8°-12°C temperature profile is present in the study lakes it is unclear if a relation exists between lake trout production in the lakes of Southwest Alaska and THV. It could be that this year was an anomaly. It is also clear from Szarzi's report (1993) that a much longer series of data needs to be collected and examined to make a proper analysis of THV and lake trout production in Southwest Alaska lakes.

BRISTOL BAY LAKE TROUT STUDY (THV) RECOMMENDATIONS

The number of lakes in the study should be reduced. Only five of the 14 lakes in the study have a harvest listed for 5 of the last 5 years in the Statewide Harvest Surveys. Only one other lake reports a harvest during 3 of the last 5 years.

Recommended lakes:

1. Brooks Lake
2. Naknek Lake
3. Ugashik Lake
4. Tikchik Lake
5. Lake Clark
6. Other lakes, with easy access for the collection of data (i.e., guides, Park Service present) should be added to this group.

At least two temperature profiles are needed each month to accurately assess THV. This profile can be taken at one location on the lake, preferably the deepest location. Temperature profiles should be at least 10 days apart.

Continue the collection of biological information. A minimum sample size of 28 lake trout weights is needed to estimate mean weight. Along with weight information we should continue to collect length, sex, and age data.

The biological samples provided by guides should be tested against biological samples collected by professional biologists when possible. This testing should be conducted to ensure that guides are providing random samples. Guides may "know" a lake better than the average fisherman and may be very adept at catching large (or small) lake trout. This would skew the estimates of mean weight and thus influence sustained yield estimates.

Surfer should be used to estimate the volume calculations. These measurements are taken from the contour maps and are likely more accurate than the method of estimation used by Payne et al. (1990).

ACKNOWLEDGMENTS

This project was a cooperative effort between the Alaska Department of Fish and Game (ADF&G), National Park Service (NPS), United States Fish and Wildlife Service (USF&WS), and the Department of Natural Resources (DNR). Many fishery professionals dedicated their time and expertise to provide the data contained in this report. In alphabetical order they are: Allen Bennett (NPS), Dan Dunaway (ADF&G), Dan Hourihan (DNR), Ron Hood (USF&WS), Ross Kavenaugh (NPS), Mark Lisac (USF&WS), Rob McDonald (USF&WS), and Rich Potts (NPS).

LITERATURE CITED

ADF&G. 1994. Alaska sport fishing regulations summary, 1994. Alaska Department of Fish and Game, Division of Sport Fish, Juneau.

Burr, J. M. 1987. Synopsis and bibliography of lake trout, *Salvelinus namaycush*, in Alaska. Alaska Department of Fish and Game, Fishery Manuscript No. 5, Juneau.

Christie, G. C. and H. A. Regier. 1988. Measures of optimal thermal habitat and their relationship to yields for four commercial fish species. Canadian Journal of Fisheries and Aquatic Sciences 45:301-314.

Cochran, W. G. 1977. Sampling techniques. Third edition. John Wily and Sons, New York.

Goodman, L. A. 1960. On the exact variance of products. Journal of the American Statistical Association 55:708-713.

LITERATURE CITED (Continued)

Mills, M. J. 1979. Alaska statewide sport fish harvest studies. Alaska Department of Fish and Game, Federal Aid in Fish Restoration, Annual Performance Report, 1978-1979, Project F-9-11, 20 (SW-1-A), Juneau.

Mills, M. J. 1980. Alaska statewide sport fish harvest studies. Alaska Department of Fish and Game, Federal Aid in Fish Restoration, Annual Performance Report, 1979-1980, Project F-9-12, 21 (SW-1-A), Juneau.

Mills, M. J. 1981a. Alaska statewide sport fish harvest studies. Alaska Department of Fish and Game (1979). Federal Aid in Fish Restoration, Annual Performance Report, 1980-1981, Project F-9-13, 22 (SW-1-A), Juneau.

Mills, M. J. 1981b. Alaska statewide sport fish harvest studies. Alaska Department of Fish and Game (1980). Federal Aid in Fish Restoration, Annual Performance Report, 1980-1981, Project F-9-13, 22 (SW-1-A), Juneau.

Mills, M. J. 1982. Alaska statewide sport fish harvest studies. Alaska Department of Fish and Game (1981). Federal Aid in Fish Restoration, Annual Performance Report, 1981-1982, Project F-9-14, 23 (SW-1-A), Juneau.

Mills, M. J. 1983. Alaska statewide sport fish harvest studies. Alaska Department of Fish and Game (1982). Federal Aid in Fish Restoration, Annual Performance Report, 1982-1983, Project F-9-15, 24 (SW-1-A), Juneau.

Mills, M. J. 1984. Alaska statewide sport fish harvest studies. Alaska Department of Fish and Game (1983). Federal Aid in Fish Restoration, Annual Performance Report, 1983-1984, Project F-9-16, 25 (SW-1-A), Juneau.

Mills, M. J. 1985. Alaska statewide sport fish harvest studies. Alaska Department of Fish and Game (1984). Federal Aid in Fish Restoration, Annual Performance Report, 1984-1985, Project F-9-17, 26 (SW-1-A), Juneau.

Mills, M. J. 1986. Alaska statewide sport fish harvest studies. Alaska Department of Fish and Game (1985). Federal Aid in Fish Restoration, Annual Performance Report, 1985-1986, Project F-10-1, 27 (RT-2), Juneau.

Mills, M. J. 1987. Alaska statewide sport fish harvest report 1986. Alaska Department of Fish and Game, Fishery Data Series No. 2, Juneau.

Mills, M. J. 1988. Alaska statewide sport fish harvest report 1987. Alaska Department of Fish and Game, Fishery Data Series No. 52, Juneau.

Mills, M. J. 1989. Alaska statewide sport fisheries harvest report 1988. Alaska Department of Fish and Game, Fishery Data Series No. 122, Juneau.

Mills, M. J. 1990. Harvest and participation in Alaska sport fisheries during 1989. Alaska Department of Fish and Game, Fishery Data Series No. 90-44, Anchorage.

Mills, M. J. 1991. Harvest, catch, and participation in Alaska sport fisheries during 1990. Alaska Department of Fish and Game, Fishery Data Series No. 91-58, Anchorage.

Mills, M. J. 1992. Harvest, catch, and participation in Alaska sport fisheries during 1991. Alaska Department of Fish and Game, Fishery Data Series No. 92-40, Anchorage.

Mills, M. J. 1993. Harvest, catch, and participation in Alaska sport fisheries during 1992. Alaska Department of Fish and Game, Fishery Data Series No. 93-42, Anchorage.

Mills, M. J. 1994. Harvest, catch, and participation in Alaska sport fisheries during 1993. Alaska Department of Fish and Game, Fishery Data Series No. 94-28, Anchorage.

Mills, M. J. and A. L. Howe. 1992. An evaluation of sport fish harvest from the Alaska Statewide Mail Survey. Alaska Department of Fish and Game, Special Publication No. 92-2, Anchorage.

Minard, R. E. and D. O. Dunaway. 1994. 1993 Area management report for the recreational fisheries of the Southwest Alaska area. Alaska Department of Fish and Game, Fishery Management Report No. 94-4, Anchorage.

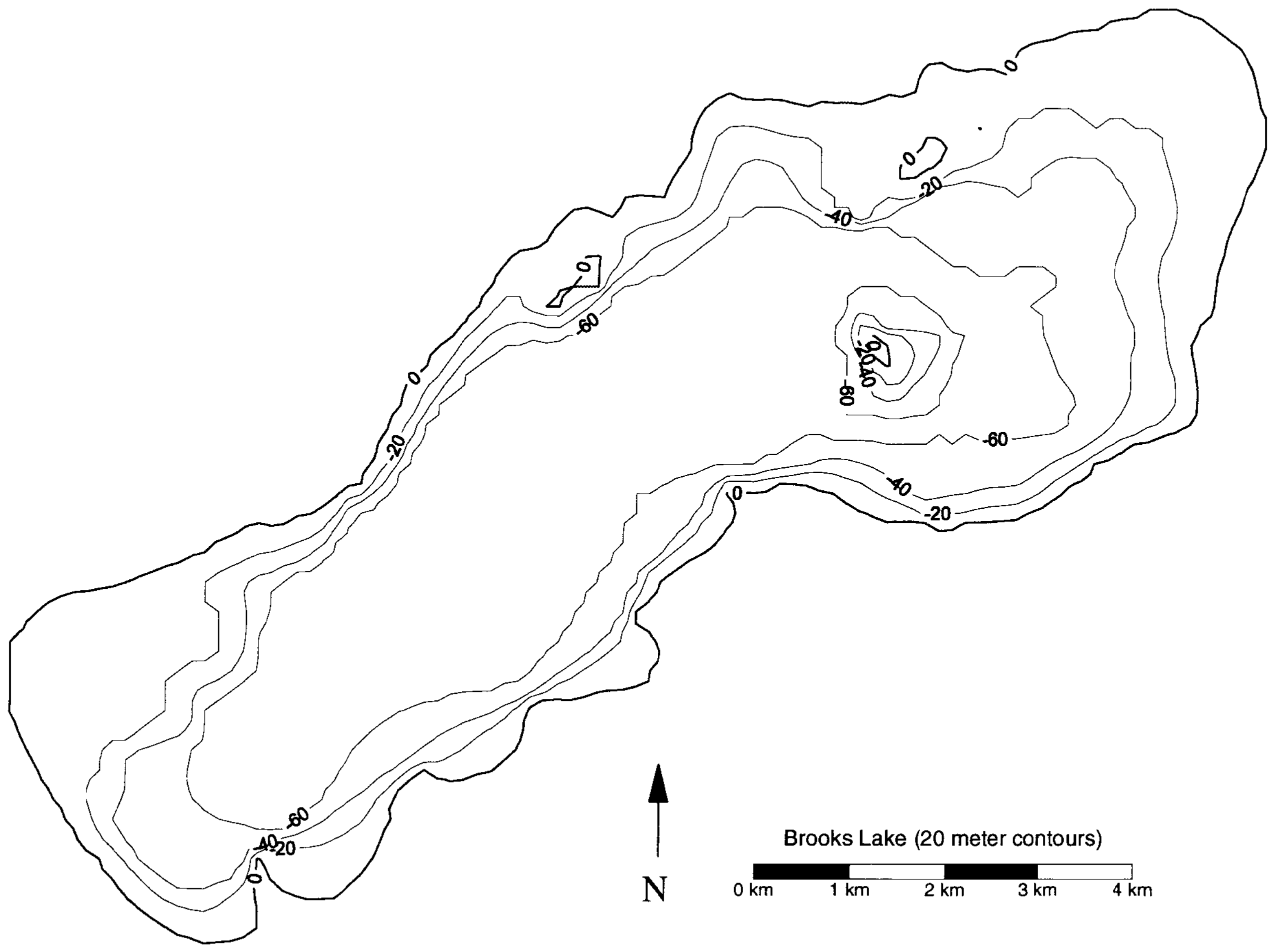
Payne, N. R., R. M. Korver, D. S. Maclennan, S. J. Nepszy, B. J. Shiter, T. J. Stewart, and E. R. Thomas. 1990. The harvest potential and dynamics of lake trout populations in Ontario. Lake Trout Synthesis Population Dynamics Working Group, Ontario Ministry of Natural Resources.

Scott, W. B. and E. J. Crossman. 1973. Freshwater fishes of Canada. Canada Fisheries Research Board Bulletin 184:220-227.

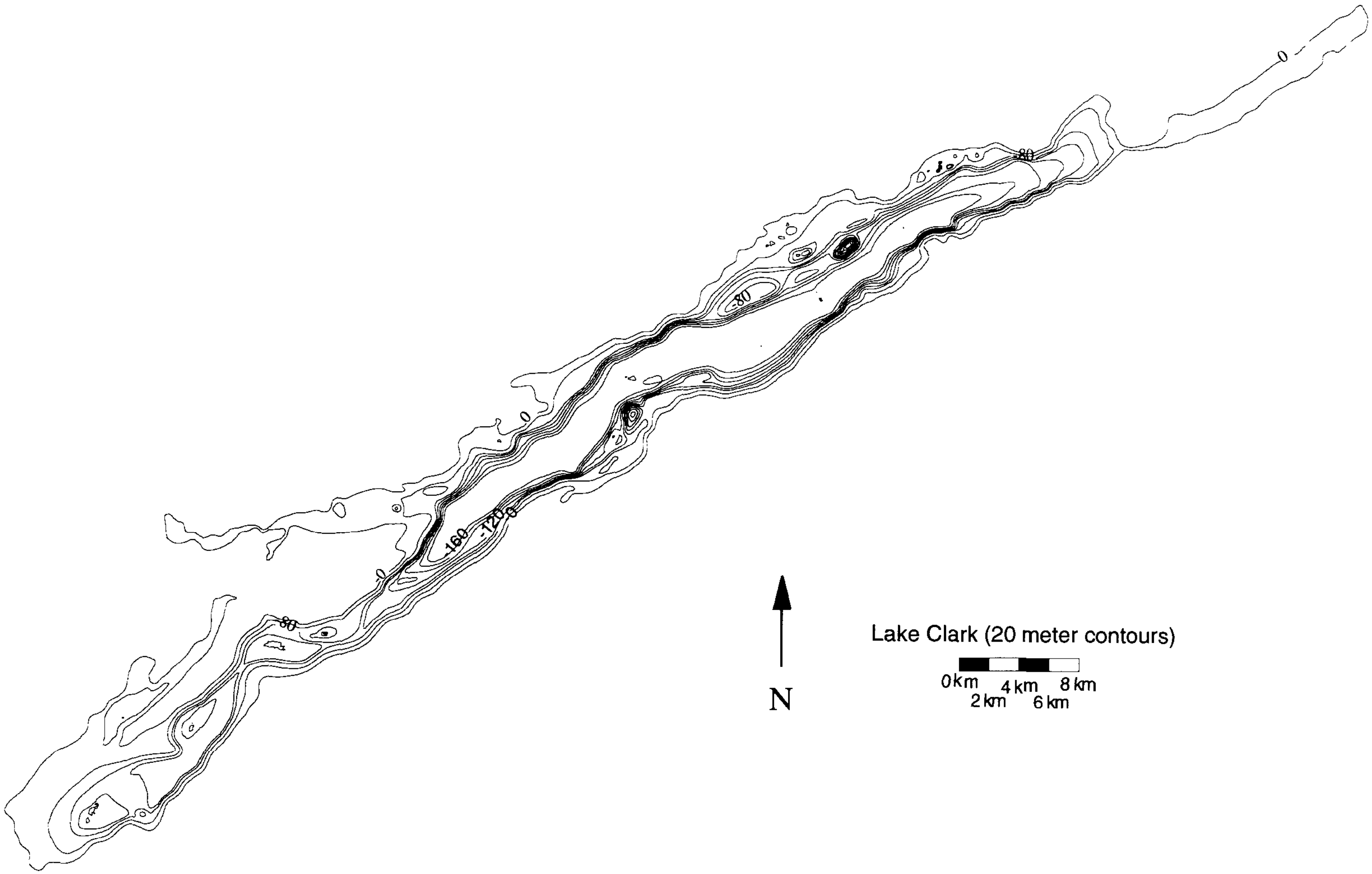
LITERATURE CITED (Continued)

Szarzi, N. J. 1993. Evaluation of lake trout stock status and abundance in selected lakes in the Upper Copper and Upper Susitna drainages. Alaska Department of Fish and Game, Fishery Data Series No. 93-48, Anchorage.

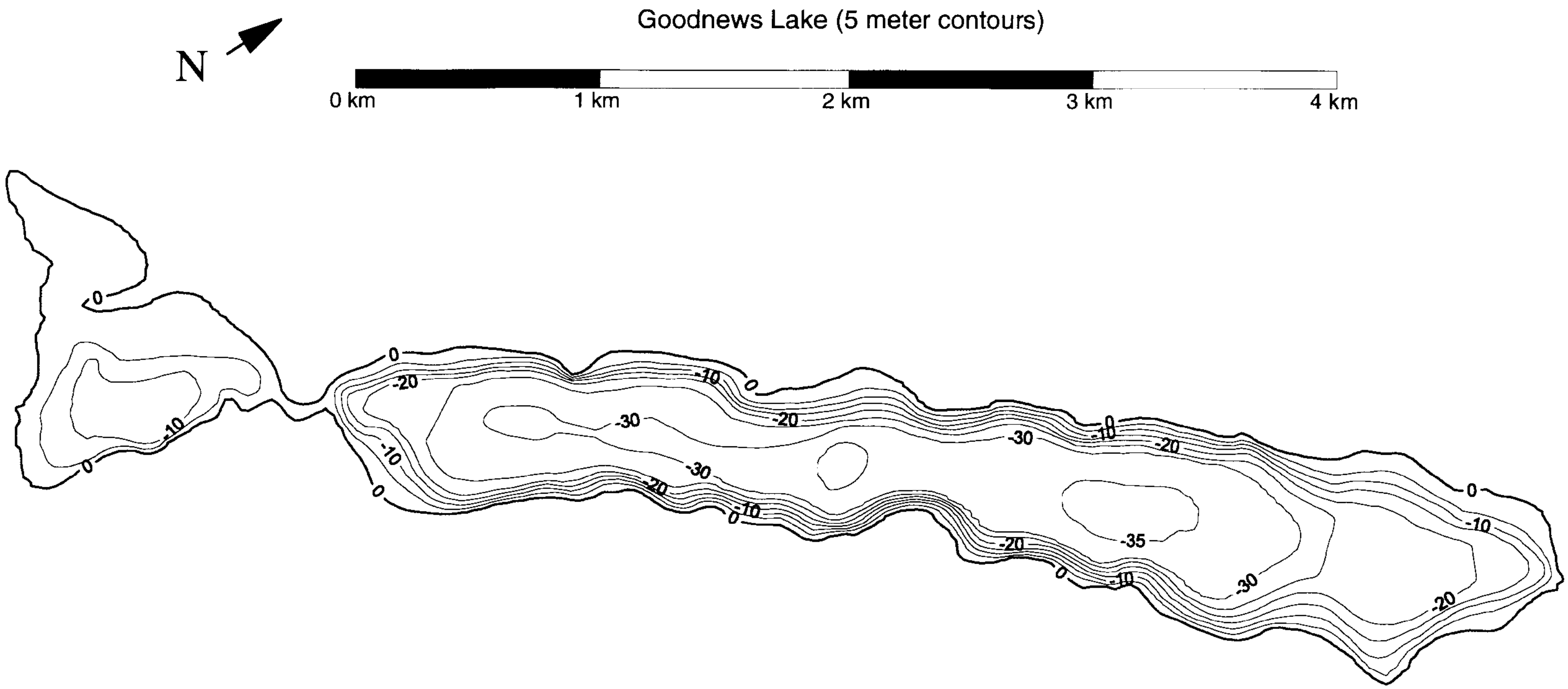
APPENDIX A. BATHYMETRIC MAPS OF STUDY LAKES



Appendix A1.-Bathymetric map of Brooks Lake.

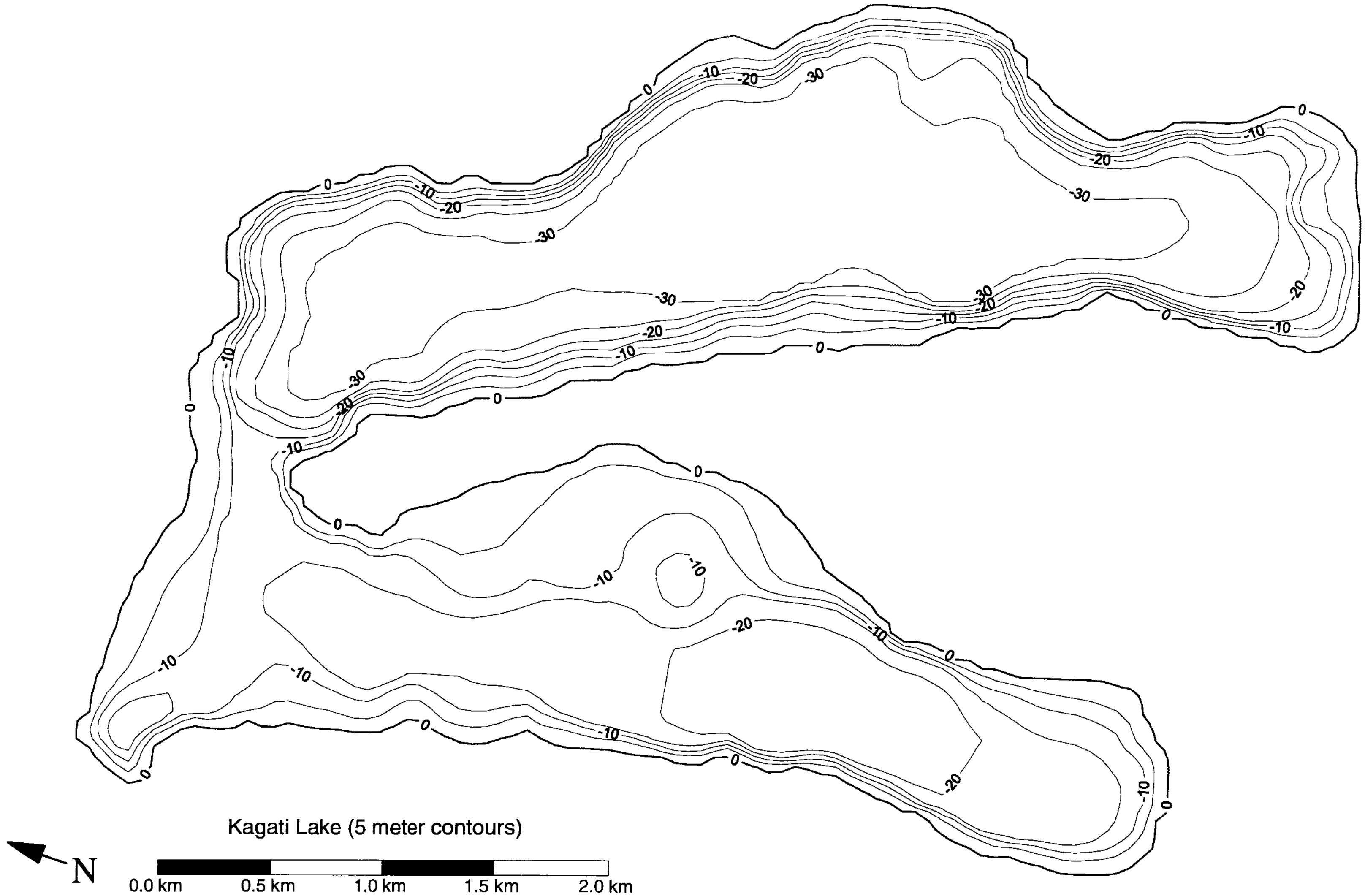


Appendix A2.-Bathymetric map of Lake Clark.

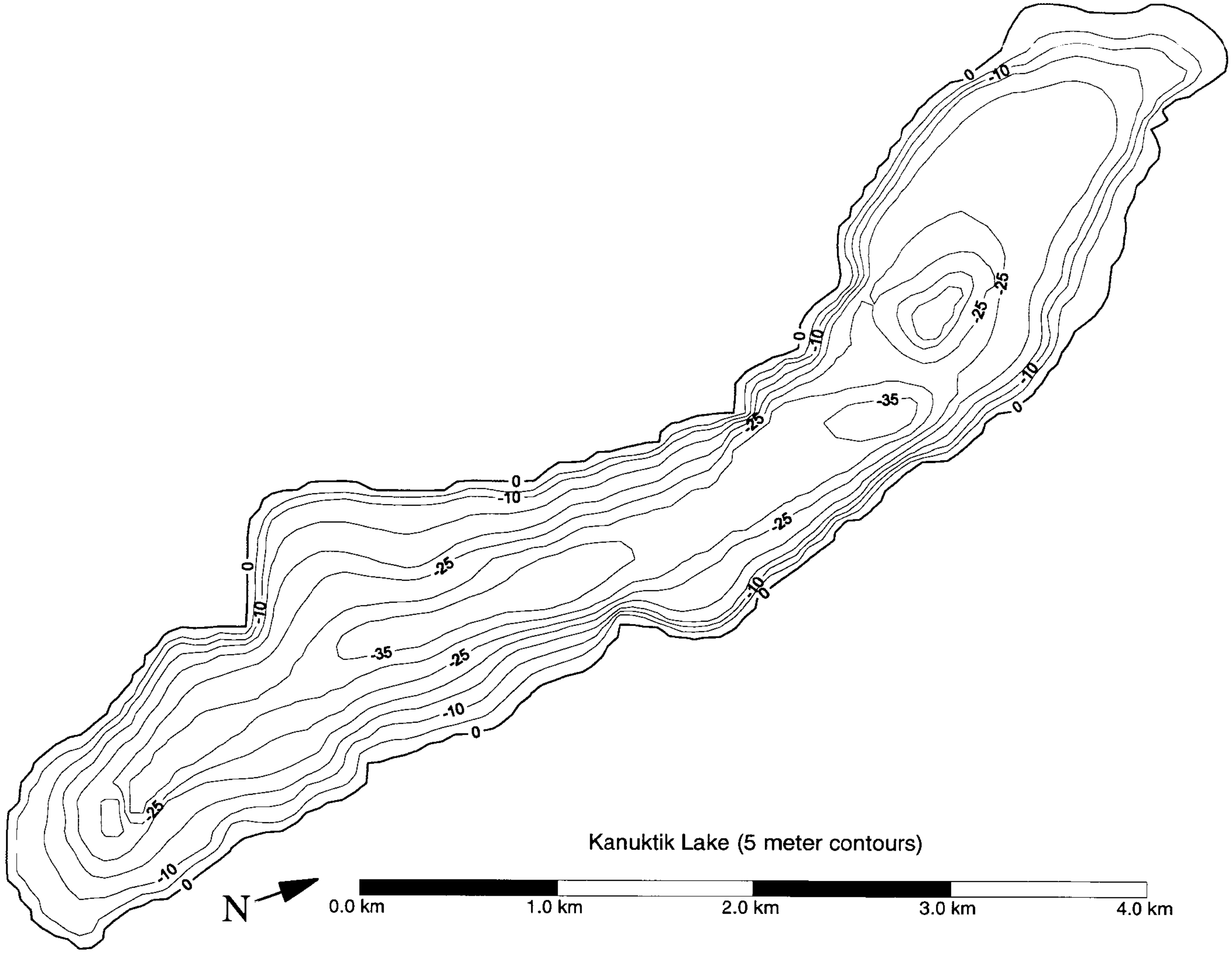


Appendix A3.-Bathymetric map of Goodnews Lake.

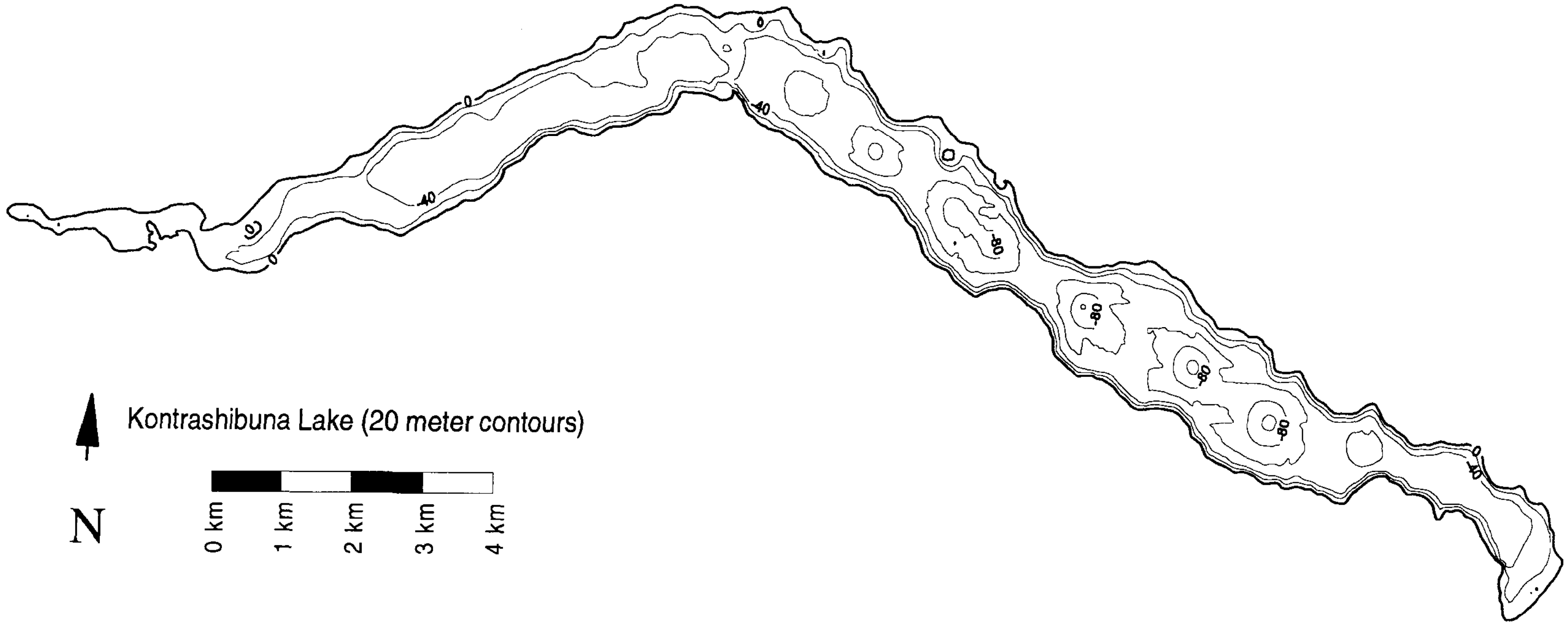
Appendix A4.-Bathymetric map of Heart Lake.



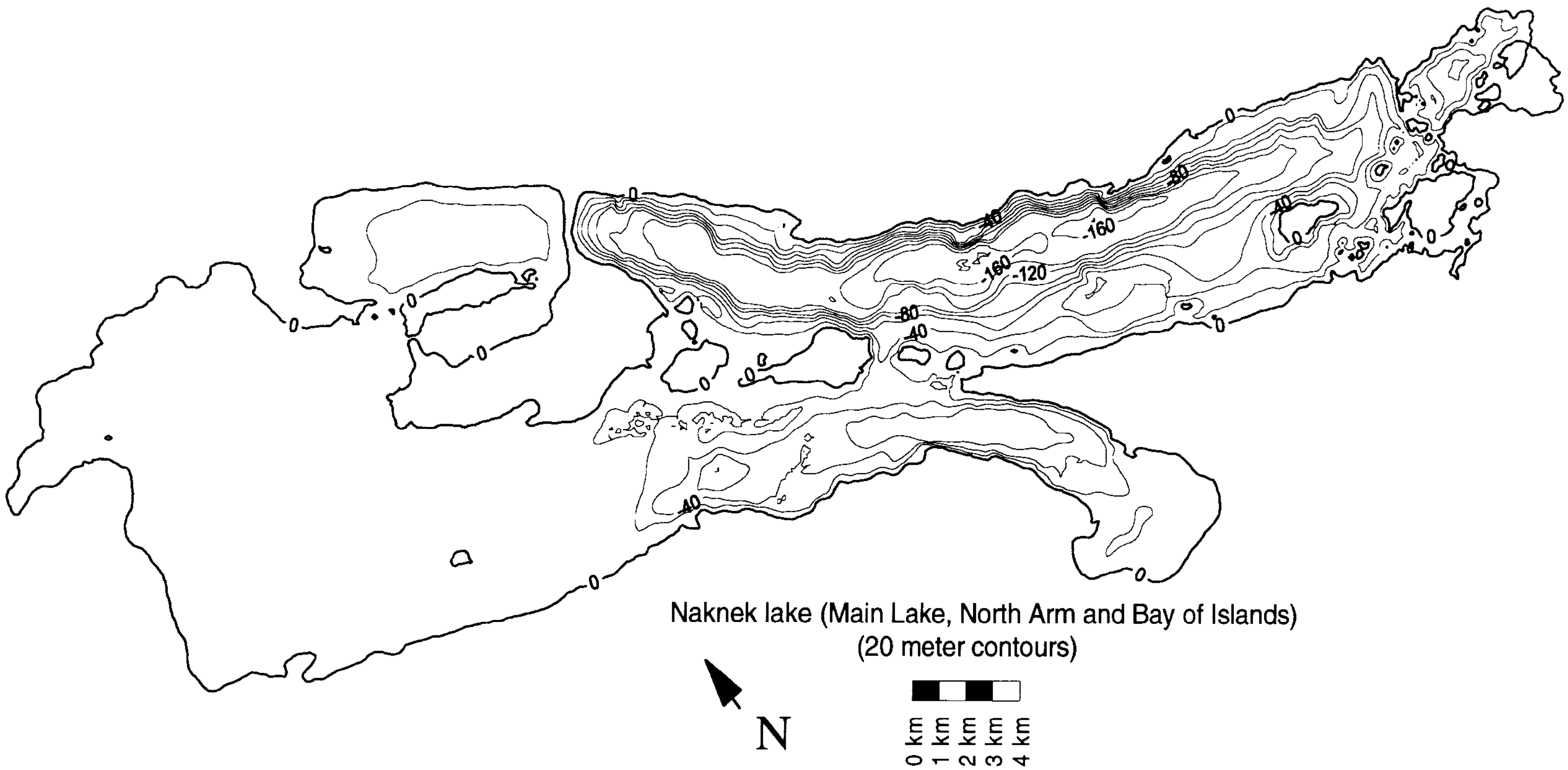
Appendix A5.-Bathymetric map of Kagati Lake.



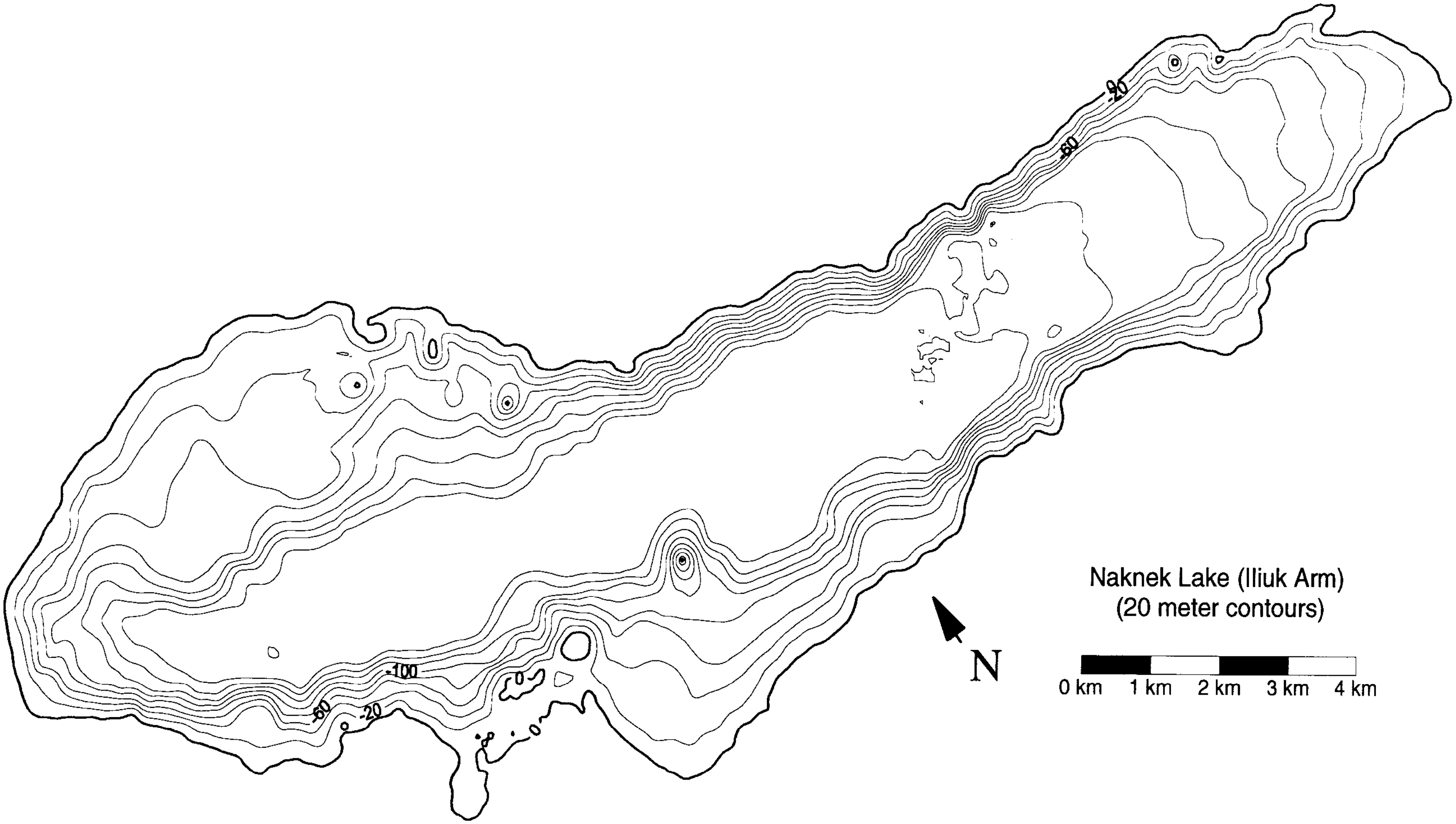
Appendix A6.-Bathymetric map of Kanuktik Lake.



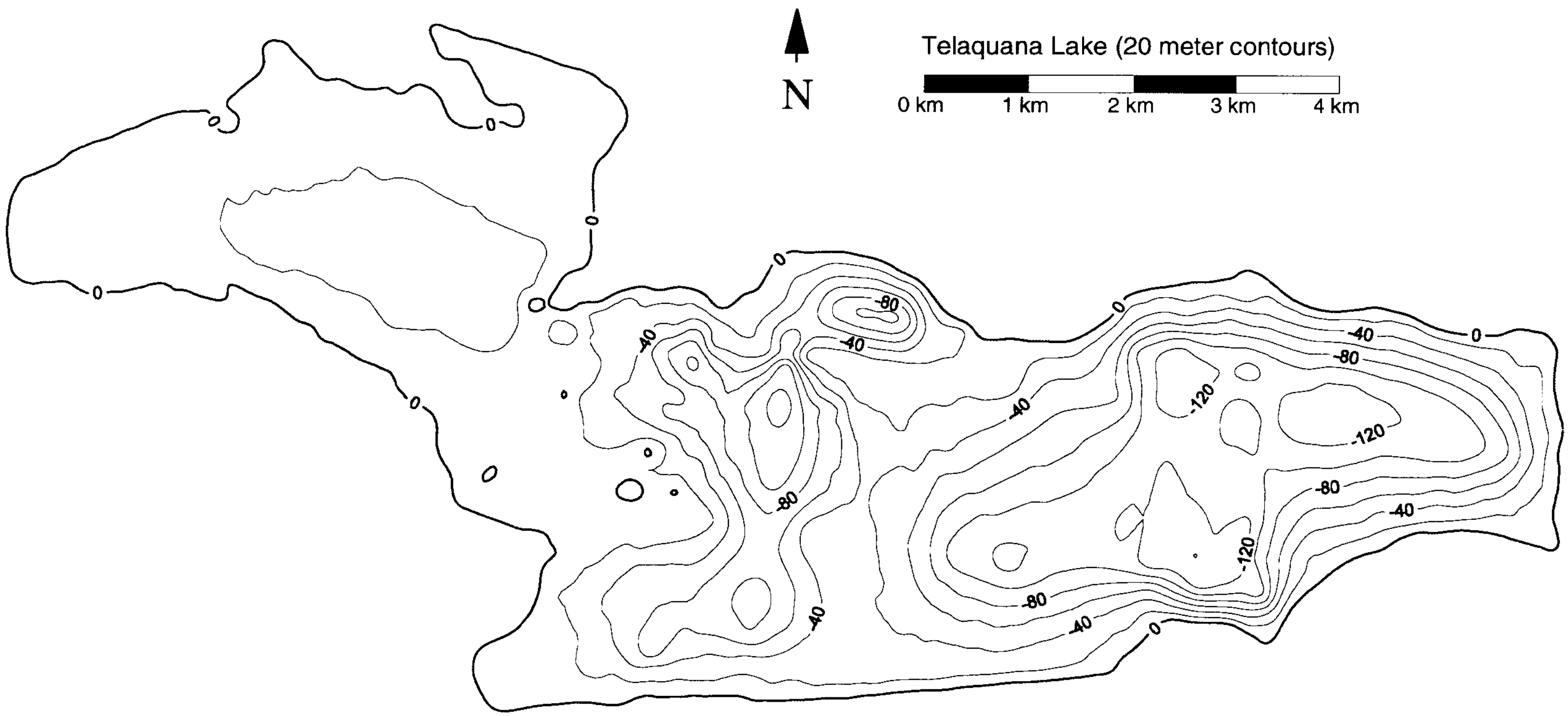
Appendix A7.-Bathymetric map of Kontrashibuna Lake.



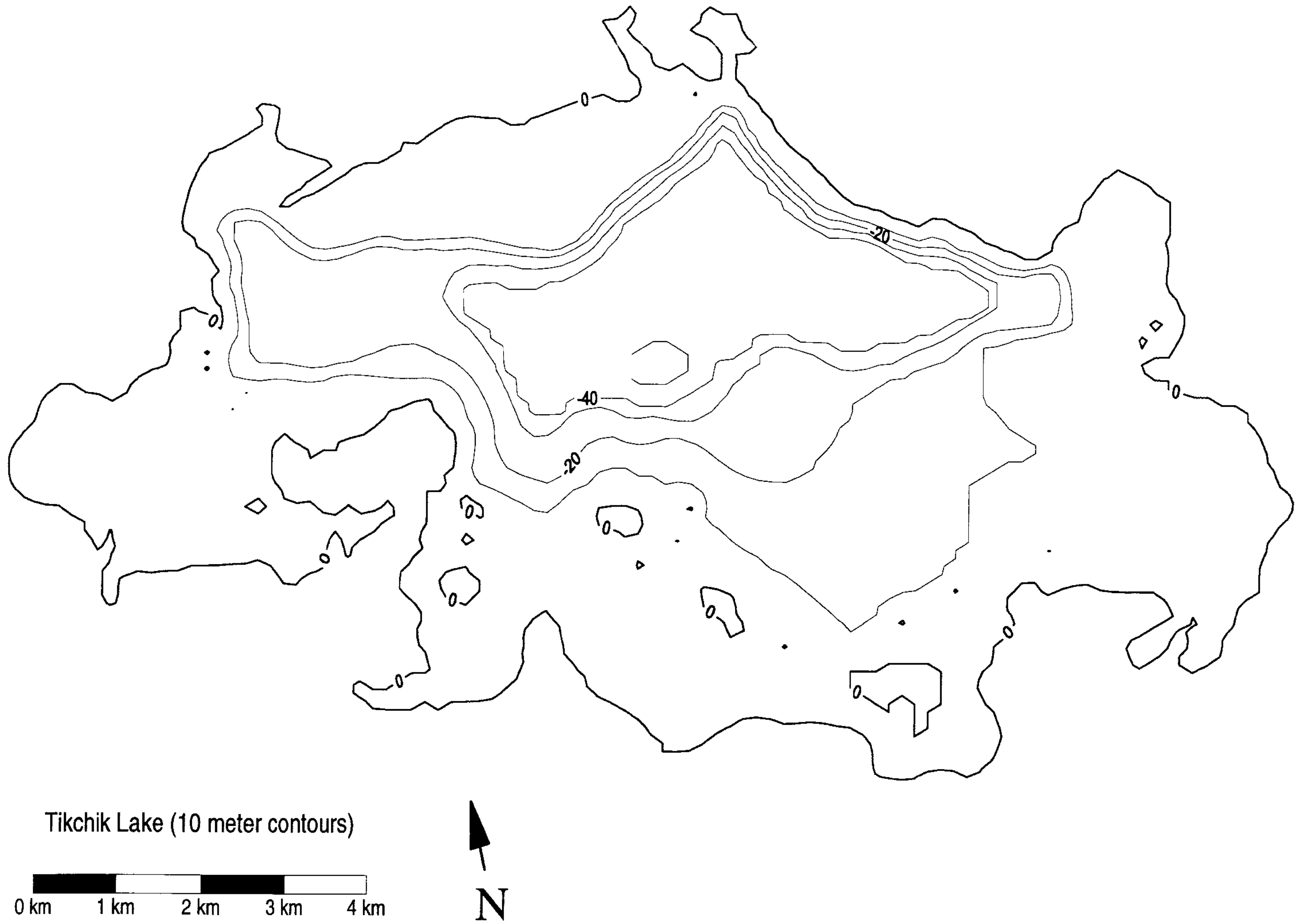
Appendix A8.-Bathymetric map of Naknek Lake, excluding Iliuk Arm.



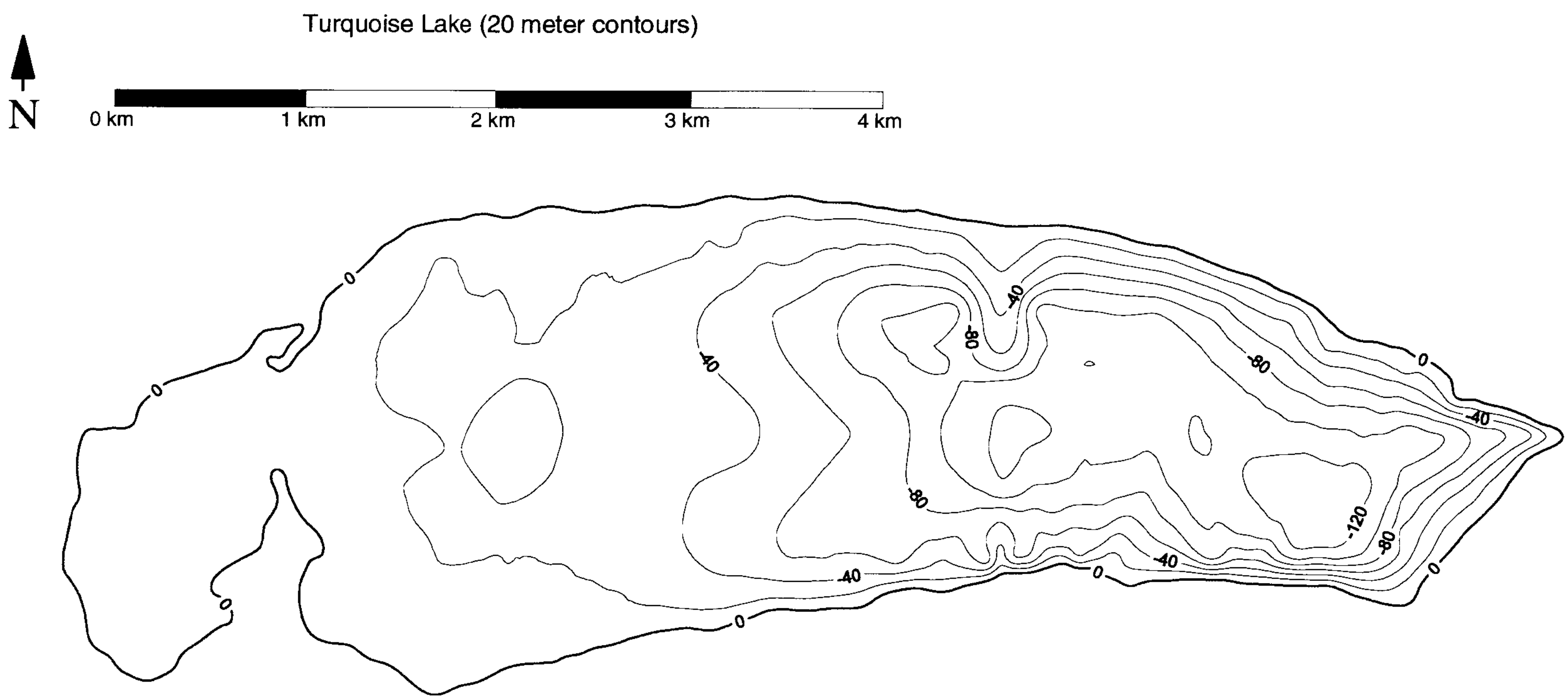
Appendix A9.-Bathymetric map of the Iliuk Arm of Naknek Lake.



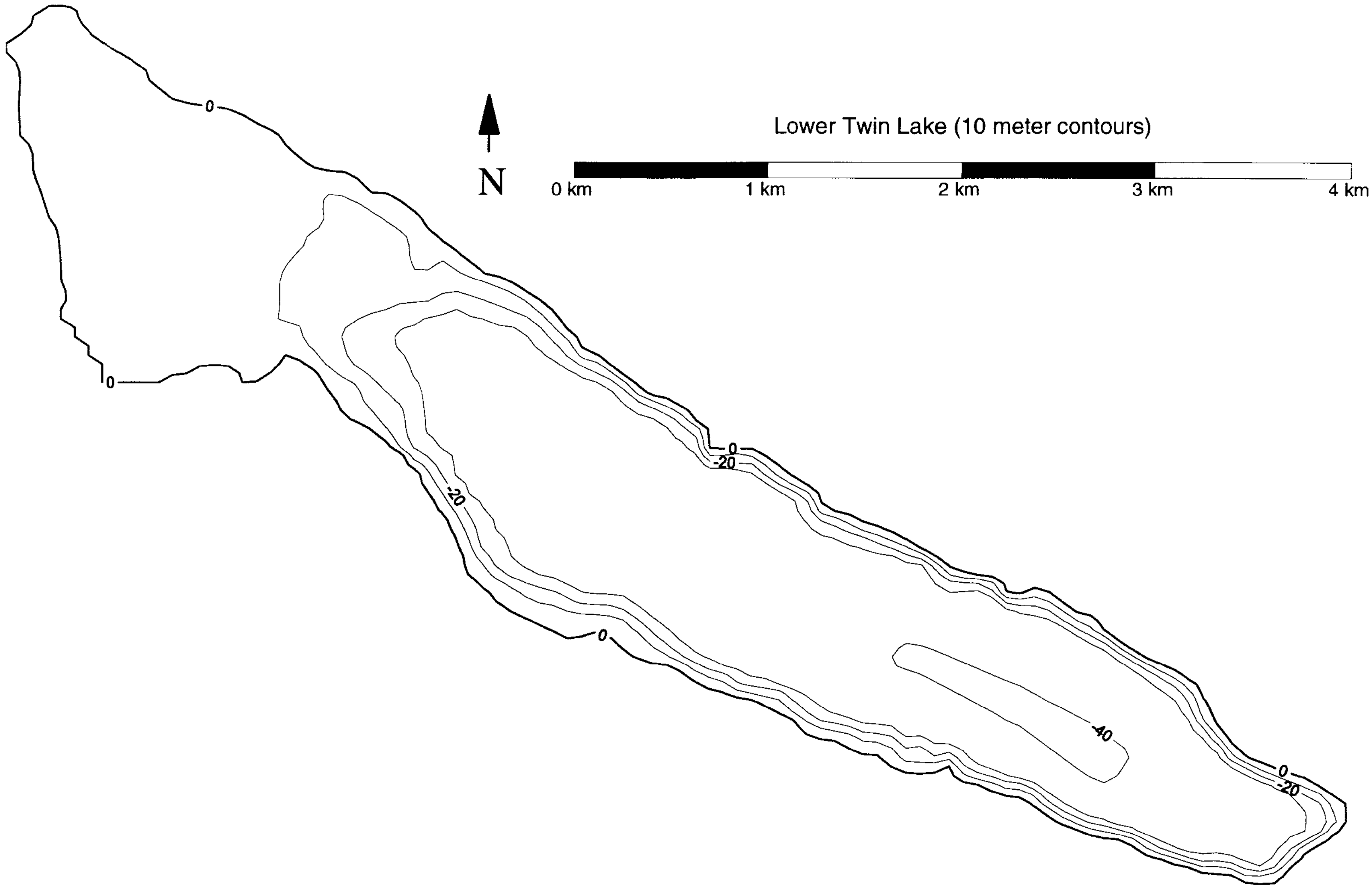
Appendix A10.-Bathymetric map of Telaquana Lake.



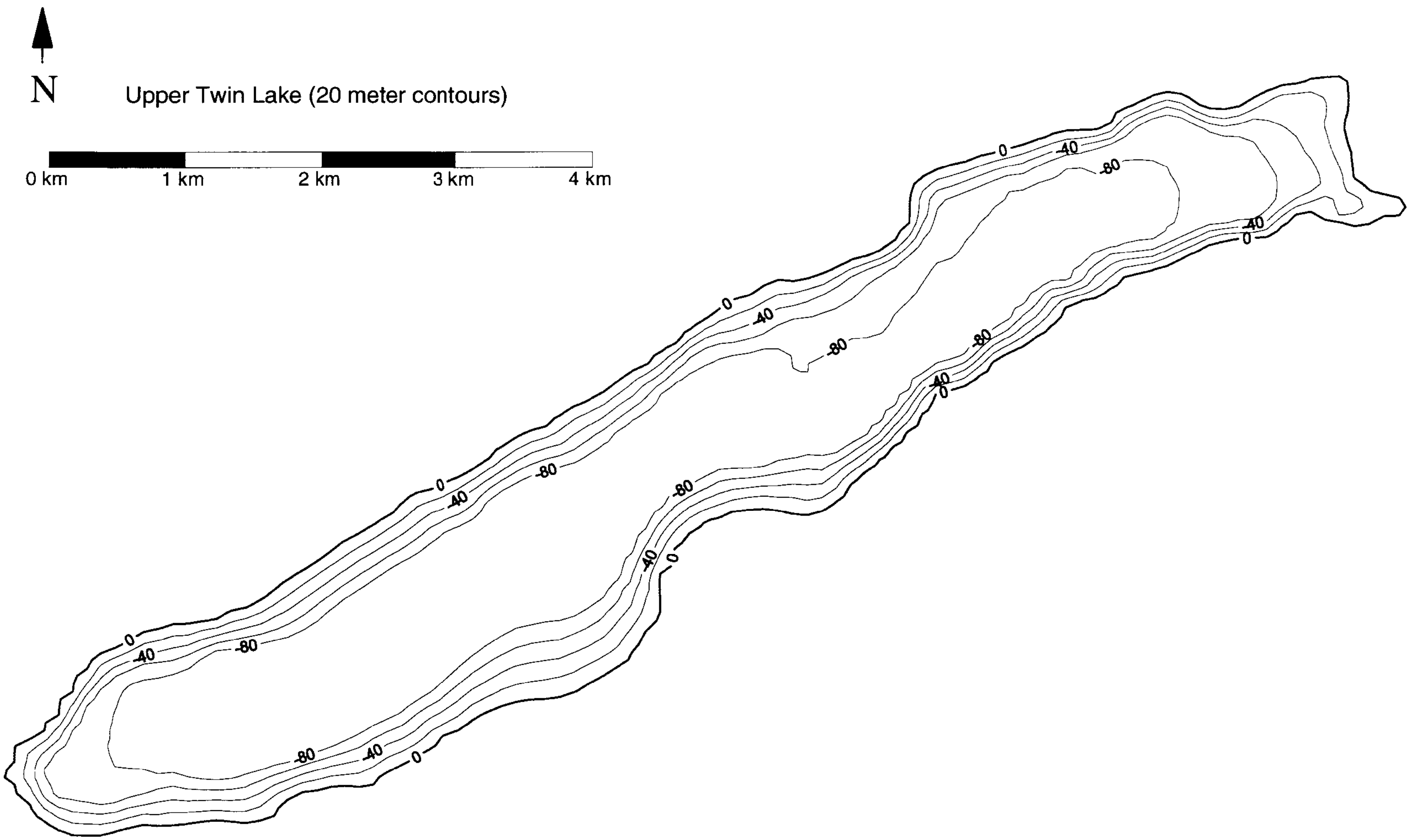
Appendix A11.-Bathymetric map of Tikchik Lake.



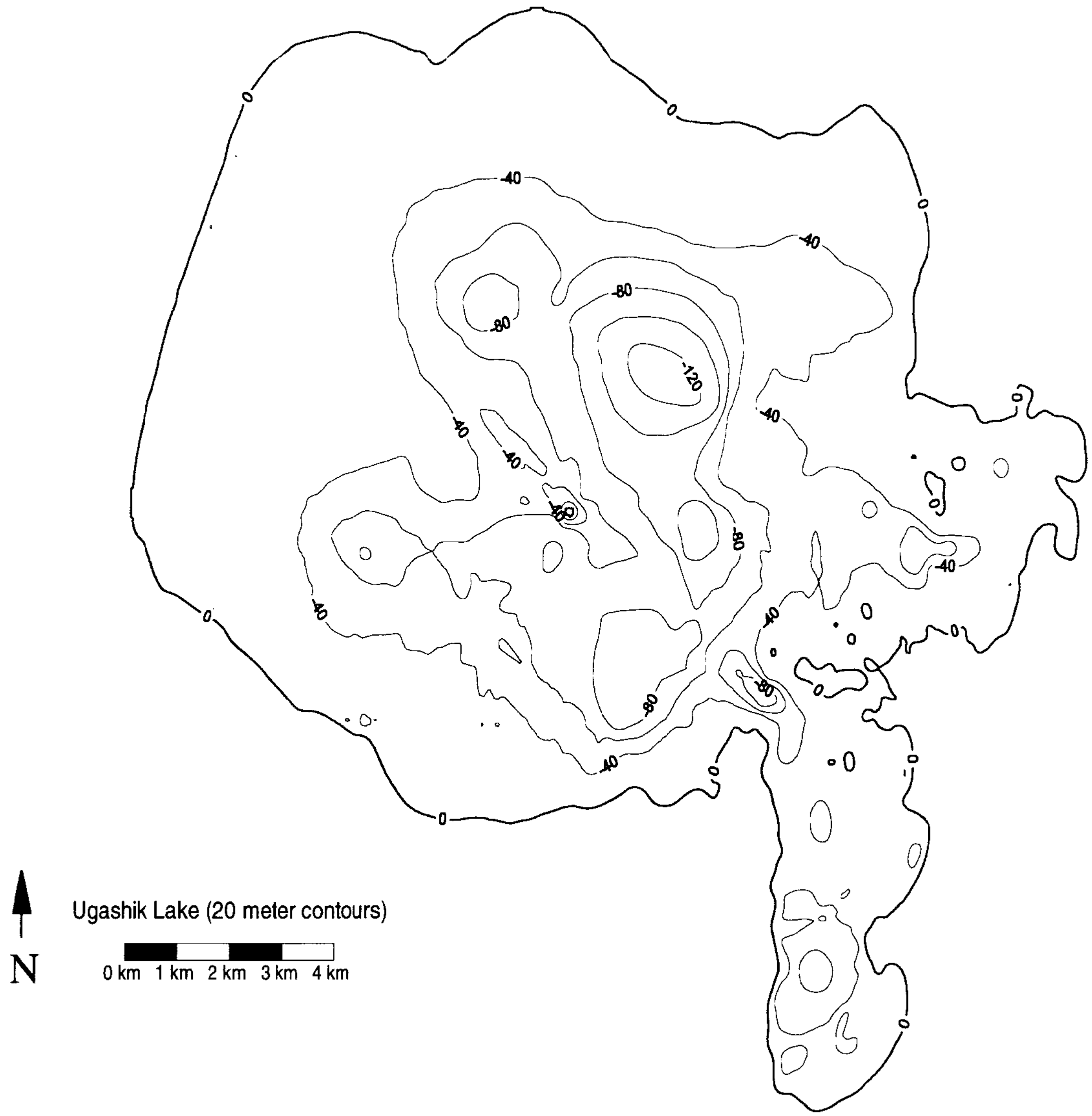
Appendix A12.-Bathymetric map of Turquoise Lake.



Appendix A13.-Bathymetric map of Lower Twin Lake.



Appendix A14.-Bathymetric map of Upper Twin Lake.



Appendix A15.-Bathymetric map of Lower Ugashik Lake.

APPENDIX B. BIOLOGICAL DATA FROM LAKES WHERE SAMPLE SIZE GOALS WERE NOT MET

Appendix B1.-Mean lengths (mm) and weights (g) of lake trout collected using hook and line methods during 1994 from lakes where sample size goals were not met.

	Telaquana Lake	Turquoise Lake	Lower Ugashik Lake
Length (mm)			
Sample Size	4	5	1
Mean	409	399	440
Standard Error	29.28	16.25	
Weight (g)			
Sample Size	5	5	1
Mean	2,282	630	1,150
Standard Error	1,434.72	40.62	

Appendix B2.-Historical biological information from the sport harvest at Goodnews Lake and Goodnews River, collected during 1975.

	Weight (g)	Fork Length (mm)
Sample Size	16	17
Mean	1,463	502
Mode	1,600	504
Standard Deviation	461	58
95% Upper Confidence Interval	1,707	532
95% Lower Confidence Interval	1,218	473
Maximum	2,350	632
Minimum	500	400

APPENDIX C. THERMAL HABITAT VOLUME AND YIELD ESTIMATES

Appendix C1.-Thermal habitat volume (THV) and sustained yield estimates using temperature profiles taken during the first temperature sampling event.

Lake	Depth (m)		Volume (hm^3)[a]		Area (ha)			THV (hm^3)[a]		Potential Harvest (kg/yr)		Potential Sustained Yield (kg/ha/yr)	
	at 12°C	at 8°C	below 12°C	below 8°C	surface	at 12°C	at 8°C	Surfer	Payne	Surfer	Payne	Surfer	Payne
Brooks	0.0	22.5	2,284	1,244	5,480	5,480	3,751	1,040	10	20,148	20,039	3.7	3.7
Naknek	5.0	25.0	12,956	8,116	47,350	39,957	16,451	4,840	5,470	60,388	65,904	1.3	1.4
Iliuk Arm	2.5	12.5	8,466	7,618	8,972	8,769	8,240	848	850	17,415	17,447	1.9	1.9
Total Naknek			21,421	15,734	56,321	48,726	24,691	5,688	6,320	67,768	73,066	1.2	1.3
Tikchik	10.0	32.5	430	85	5,892	2,455	841	345	355	9,159	9,351	1.6	1.6
Lake Clark	5.0	17.5	24,931	21,769	30,659	27,001	23,792	3,163	3,172	44,569	44,668	1.5	1.5
Kontrashibuna	2.5	27.5	912	425	2,345	2,246	1,673	487	488	11,715	11,739	5.0	5.0
Lower Twin	0.0	30.0	186	25	831	831	394	162	180	5,336	5,754	6.4	6.9
Upper Twin	0.0	12.5	938	760	1,503	1,503	1,360	178	179	5,717	5,732	3.8	3.8
Turquoise	0.0	6.0	578	502	1,300	1,300	1,180	75	74	3,086	3,063	2.4	2.4
Telaquana	2.5	20.0	1,912	1,267	4,632	4,558	2,889	646	646	14,332	14,340	3.1	3.1
Goodnews	0.0	17.5	69	21	382	382	207	48	51	2,227	2,333	5.8	6.1
Heart	0.0	25.0	100	14	565	565	157	86	85	3,400	3,371	6.0	6.0
Kagati	0.0	20.0	188	36	1,057	1,057	462	152	148	5,102	5,004	4.8	4.7
Kanuktik	0.0	20.0	151	29	807	807	410	122	119	4,363	4,296	5.4	5.3
Lower Ugashik	2.5	45.0	6,105	1,342	17,693	17,553	5,864	4,763	4,755	59,705	59,630	3.4	3.4

[a] hm^3 = cubic hectometers.

Appendix C2.-Thermal habitat volume (THV) and sustained yield estimates using temperature profiles collected during the second sampling event.

	Depth(m)		Volume (hm³) [a]		Area (ha)			THV (hm³) [a]		Potential Harvest (kg/yr)		Potential Sustained Yield (kg/ha/yr)	
Lake	at 12°C.	at 8°C	below 12°C	below 8°C	surface	at 12°C	at 8°C	Surfer	Payne	Surfer	Payne	Surfer	Payne
Brooks	12.5	27.5	1,662	1,061	5,480	4,546	3,568	601	607	13,624	13,716	2.5	2.5
Naknek	17.5	35.0	9,493	6,643	47,350	20,559	13,453	2,850	2,954	41,377	42,451	0.9	0.9
Iliuk Arm	0.0	25.0	8,687	6,621	8,972	8,972	7,698	2,067	2,082	32,892	33,064	3.7	3.7
Total Naknek			18,181	13,264	56,321	29,530	21,151	4,917	5,036	61,072	62,127	1.1	1.1
Tikchik	15.0	30.0	324	107	5,892	1,925	988	217	215	6,575	6,527	1.1	1.1
Lake Clark	10.0	25.0	23,617	20,043	30,659	25,576	22,270	3,573	3,586	48,628	48,748	1.6	1.6
Kontrashibuna	12.5	32.5	701	344	2,345	1,999	1,565	357	356	9,392	9,362	4.0	4.0
Lower Twin	10.0	30.0	118	25	831	554	393	93	94	3,603	3,628	4.3	4.4
Upper Twin	0.0	15.0	938	726	1,503	1,503	1,337	212	213	6,470	6,490	4.3	4.3
Turquoise	1.0	10.0	565	458	1,300	1,293	1,073	107	106	3,975	3,954	3.1	3.0
Telaquana	5.0	22.5	1,800	1,196	4,632	4,378	2,722	604	616	13,661	13,853	2.9	3.0
Goodnews	10.0	20.0	39	16	382	256	191	22	22	1,291	1,296	3.4	3.4
Heart	17.5	30.0	31	7	565	272	120	25	24	1,391	1,360	2.5	2.4
Kagati	0.0	25.0	188	16	1,057	1,057	341	173	166	5,589	5,445	5.3	5.2
Kanuktik	0.0	37.5	151	0	807	807	0	151	103	5,083	3,873	6.3	4.8
Lower Ugashik	0.0	57.5	6,546	756	17,693	17,693	3,699	5,790	5,651	68,634	67,452	3.9	3.8

[a] hm^3 = cubic hectometers.