FRED Reports

FINGER LAKE WATER QUALITY:
AUGUST 1988

by
J. A. Edmundson[1], J. P. Koenings[1]
and
T. C. Wilson[2]

Number 92

Alaska Department of Fish & Game
Division of Fisheries Rehabilitation,
Enhancement and Development

FINGER LAKE WATER QUALITY: AUGUST 1988

by
J. A. Edmundson[1], J. P. Koenings[1]
and
T. C. Wilson[2]

Number 92

Alaska Department of Fish and Game
Division of Fisheries Rehabilitation,
Enhancement and Development

Don W. Collinsworth
Commissioner

Brian J. Allee, Ph.D.
Director

P.O. Box 3-2000
Juneau, Alaska 99802-2000

February 1989

---

[1] Alaska Department of Fish and Game, FRED Division, Soldotna.

[2] Alaska Department of Environmental Conservation, Wasilla.

TABLE OF CONTENTS

TABLE OF CONTENTS (continued)

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

Finger Lake has a long history as a popular recreational resource for residents around the city of Wasilla, and in recent years the watershed has been extensively developed. During the spring of 1988, public concern arose over changes in water quality because of visible changes in Finger Lake's water clarity. In response to this concern, a comprehensive limnological survey was conducted between 17 and 30 August 1988 by the Alaska Department of Fish and Game and the Department of Environmental Conservation.

As a result of high nutrient levels and favorable climatic conditions during the summer of 1988, Finger Lake experienced blooms of the blue-green algae *Oscillatoria* sp. and *Lyngbya* sp. within the epilimnion. Moreover, epilimnetic total phosphorus (40.9 ug/L) and chlorophyll a (14.7 ug/L) levels were high while inorganic nitrogen concentrations (<12 ug/L) and light penetration (Secchi disk 1.8 m) were low. We also observed oxygen depletion (<0.5 mg/L) and the presence of ammonia (21.5 ug/L) and hydrogen sulfide (44.7 ug/L) gases at levels toxic to fish and aquatic life within the hypolimnion.

Both the limited historical record and current water quality indicates Finger Lake is a highly productive or eutrophic system. Given the current highly productive nature of Finger Lake, periodic summer blooms of nuisance algae will likely continue.

KEY WORDS: Water quality, hydrogen sulfide, ammonia, eutrophic, blue-green, algal blooms, oxygen depletion.

INTRODUCTION

During the early summer of 1988, local residents complained of sudden changes in the water clarity of Finger Lake near Palmer, Alaska. Specifically, the water turned an uncharacteristic brown color that was most visible during the months of July and August. In addition, one investigator reported skin irritation, perhaps attributable to the larval stage of the parasitic bird blood flukes commonly known as "swimmers itch". Finger Lake provides a sportfishing and recreational resource for nearby residents which includes the Alaska Department of Natural Resources's Finger Lake Wayside, dock, boat ramp; and private resorts. A cooperative preliminary investigation was initiated by the Alaska Department of Fish and Game (ADF&G) and the Department of Environmental Conservation (DEC) to assess the current water quality and determine possible causes for the observed changes occurring within Finger Lake.

Study Site Description

Finger Lake is located within the Matanuska-Susitna Valley approximately 35 mi northeast of Anchorage and 5 mi west of the city of Palmer (Figure 1). This shallow, seepage lake is readily accessible by road, and is situated within a low-lying drainage area surrounded by numerous residential homesites. As of 1988, 68 shoreline tracts (37%) were occupied with year-round residences and an additional 54 tracts were occupied in nearby subdivisions. Since 1982, DEC has required septic systems installed with sand filters because of very permeable soils and shallow water table (<10 m). Resident sportfish species include stocked coho salmon (*Oncorhynchus kisutch*), rainbow trout (*Salmo gairdneri*), and Arctic grayling (*Thymallus arcticus*). In addition, Finger Lake supports threespine stickleback (*Gasterosteus aculeatus*).

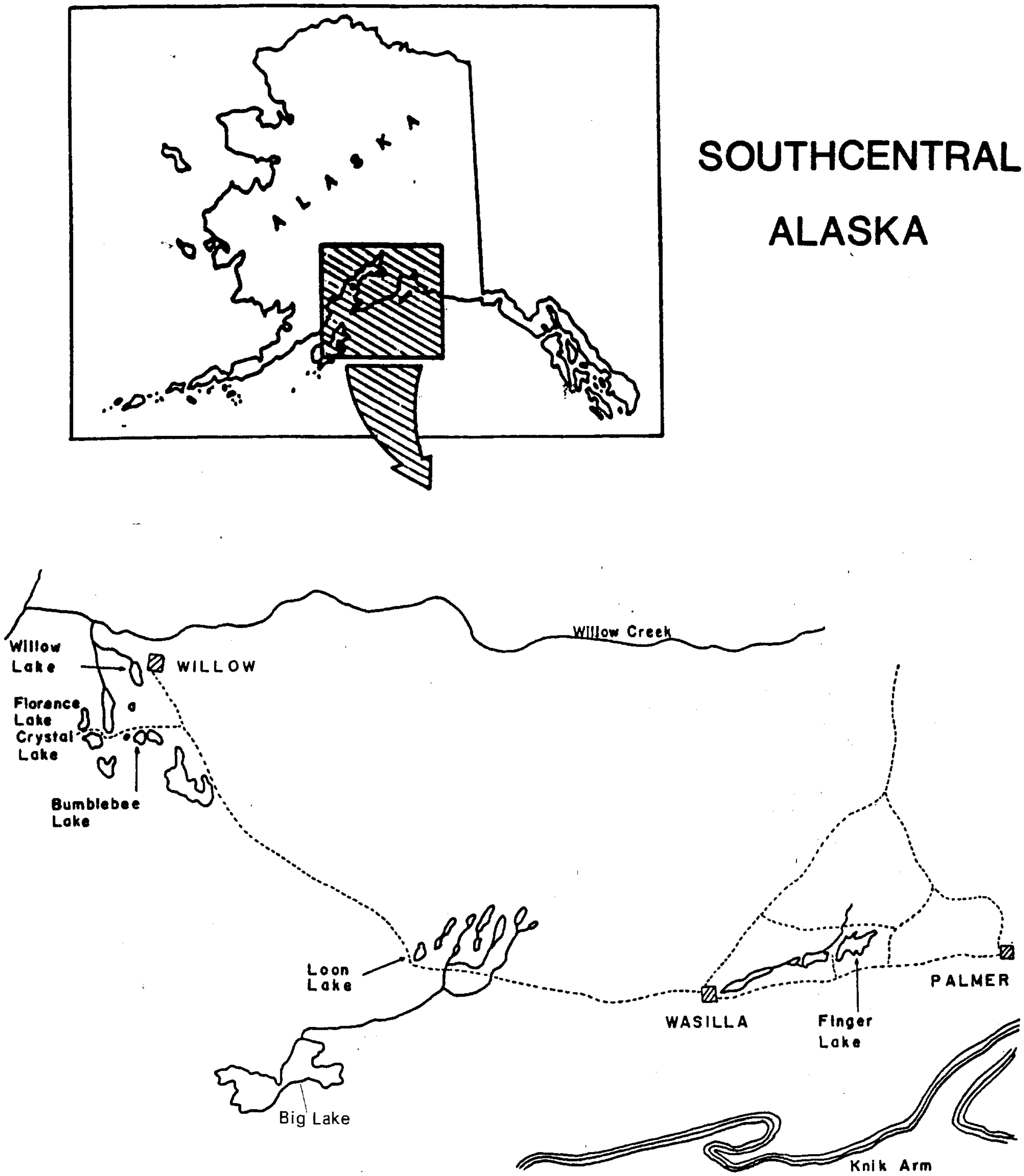

Figure 1. Area map of Southcentral Alaska showing the locations of Finger Lake and nearby Big Lake within the Matanuska-Susitna River Valley

METHODS AND MATERIALS

To assess the water quality of Finger Lake; algal, zooplankton, and bacterial samples were collected by DEC and ADF&G personnel in conjunction with various physical and chemical measurements over a two-week period from 17-30 August 1988. Laboratory analysis of nutrient, chlorophyll a (chl a), and zooplankton samples were carried out by the ADF&G, Limnology laboratory in Soldotna, Alaska. Phytoplankton identification and enumeration were conducted by Eco-Logic, Ltd. in West Vancouver, British Columbia; and fecal coliform bacteria analysis was completed by the DEC laboratory in Wasilla, Alaska.

Field Sampling

Field data and samples were collected from various near-shore and mid-lake sites (Figure 2). Temperatures were recorded on two occasions within the deep NW basin; 1) at 0.3-m intervals from the surface to the lake bottom using a Hydrolab 4000 analyzer (17 August); and 2) at 1-m intervals in combination with measurements of conductivity using a YSI model 33 meter (30 August). Measurements of light penetration (footcandles) were recorded 17 August at 0.5-m intervals from the surface to the lake bottom using a Protomatic submarine photometer. Euphotic zone depth was defined as the depth to which 1% of the subsurface light [(photosynthetically available radiation (400-700 nm)] penetrates (Schindler 1971). In addition, Secchi disk transparency was determined 30 August by lowering and raising the standard 20-cm (8-in) black and white, circular plate.

Dissolved oxygen concentrations within the deep basin were determined 18 August from samples collected at ~1.0-m intervals from the surface to just above the lake bottom using the Winkler method (dropwise titration with 0.019 N phenylarsine oxide). In addition, lake water samples were collected 30 August from varying depths within the deep basin, 'fixed' with p-

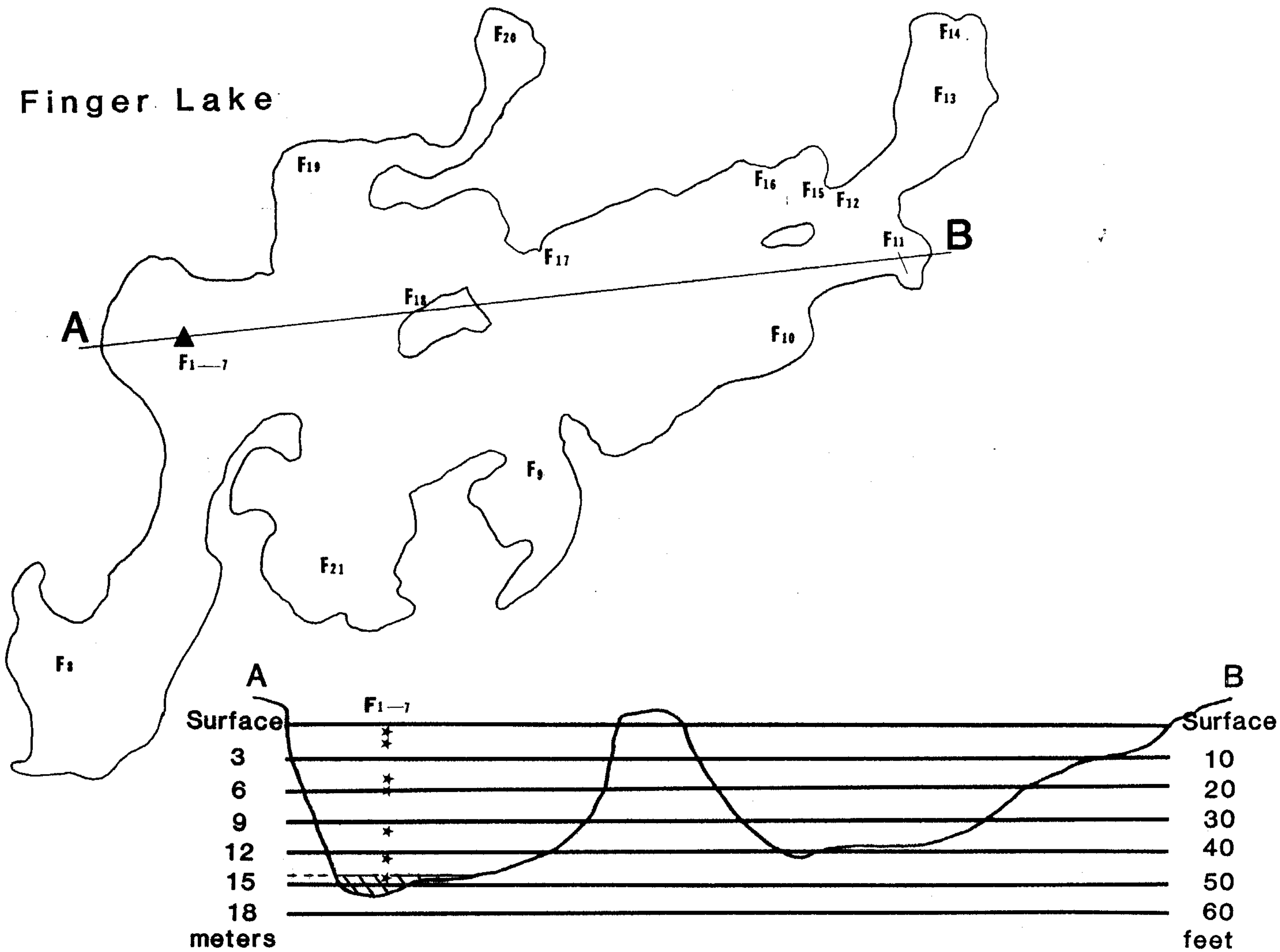

Figure 2. Outline of Finger Lake showing the main limnology sampling station (▲) within the deep basin and the sites sampled for fecal coliform (F1-21). Also shown is a cross-section of Finger Lake through the transect A--B. Diagonal lines indicate the ambiguity in maximum lake depth between current and historical data.

phenylenediamine and ferric chloride, and analyzed for total sulfide by measuring the spectrophotometric absorbance at 600 nm. The proportions of total sulfide as the undissociated H_2S were calculated based on insitu pH measurements (Orion model 201 pH meter) at corresponding depths after APHA (1985).

Water quality samples used to characterize the epilimnion and hypolimnion were collected 17 August from the 1.0-m stratum, mid-epilimnion, and mid-hypolimnion within the deep basin using a brass Kemmerer sampler. The 8-liter (2-gal) bulk samples were stored in pre-cleaned polyethylene carboys, packed in ice, returned to the limnology laboratory within 24 hr, and prepared for chemical analysis. That is, upon receipt by the lab, separate sub-samples from each carboy were; 1) refrigerated for general tests and metals analysis; 2) frozen until analyzed for total nitrogen and phosphorus; and 3) filtered through a Whatman 4.5-cm GF/F glass-filter and frozen until analyzed for dissolved nutrients (Koenings et al. 1987).

Laboratory Analysis

General Water Quality

Turbidities (NTU) were determined using a model DRT-100 laboratory turbidimeter. Water color was determined on a filtered sample by measuring the spectrophotometric absorbance at 400 nm and converting to equivalent platinum cobalt units (Pt) using a standard calibration curve (Koenings et al. 1987). Conductivities (temperature compensated to 25°C) were measured using a model YSI 32 conductance meter; and pH measured with an Orion 399A ionanalyzer.

Metals

Calcium and magnesium were determined from separate EDTA (0.01 N) titrations after Golterman (1970). Total iron was analyzed by reduction of ferric iron with hydroxylamine during hydrochloric acid digestion after Strickland and Parsons (1972).

Nutrients

Filterable and reactive phosphorus were determined using the molybdenum-blue method as modified by Eisenreich et al. (1975). Total phosphorus utilized the same procedure following acid-persulfate digestion. Nitrate (NO^-_3) + nitrite (NO^-_2) were determined as nitrite following cadmium reduction of nitrate, and total ammonia was determined using the phenolhypochlorite procedure after Stainton et al. (1977). In addition, the proportion of total ammonia (i.e., NH_3 + NH^+_4) present as the toxic NH_3 were calculated using insitu temperature and pH values after Emerson et al. (1975). Total Kjeldahl nitrogen was determined as total ammonia following sulfuric acid block digestion (Crowther et al. 1980). Reactive silicon was determined using ascorbic acid reduction to molybdenum-blue (Stainton et al. 1977), and alkalinities were determined by sulfuric acid (0.02 N) titration to pH 4.5.

Phytoplankton (algae)

Algal species were enumerated from samples preserved in a mild solution of Lugol's acetate (Koenings et al. 1987) using phase contrast microscopy. Samples for chl a analysis were prepared by filtering a known volume of lake water through a 4.25-cm GF/F filter to which ~2 ml of 1 N $MgCO_3$ were added prior to completion. Filters were then stored frozen in individual plexiglas slides until analyzed. Chl a (corrected for inactive phaeophytin) was determined by direct fluorometric analysis of Strickland and Parsons (1972) with the dilute acid addition after Reimann (1978).

Zooplankton

Replicate bottom-to-surface vertical zooplankton hauls were taken 17 August from the deep basin using a 0.2-m diameter, 153 um mesh, conical zooplankton net. The net was pulled at a constant 1 m/s, rinsed prior to removing the organisms and preserved in a solution of 10% formalin (Koenings et al. 1987). *Daphnia* sp. were identified according to Brooks (1957), rotifers after Pennak (1978), and copepods after Wilson (1959) and Yeatman (1959). Zooplankton were enumerated from three 1-ml subsamples taken with a Hensen-Stemple pipet and placed in a 1-ml Sedgewick-Rafter cell. Zooplankton body sizes from 30 organisms of each species were measured to the nearest 0.01 mm along a transect in each of the 1-ml subsamples using a calibrated ocular micrometer (Koenings et al. 1987).

Fecal Coliform Bacteria

Samples for fecal coliform bacteria analysis were collected 17, 24, and 30 August at the surface from several near-shore sites; and from the surface, 1, 4.75, 6, 9.75, 12.5, and 13-m strata within the deep basin (Figure 2). Analysis followed the standard fecal coliform membrane filter procedure 909-C (APHA 1985). Membrane filters were prepared by filtering 100 ml of lake water and placed on a sterile pad to which 1-2 ml of M-FC medium were added. Filters were incubated for 24 hr at 44.5°C and the colonies counted directly.

Conversion Factors

To facilitate a better understanding of analytical results, the units of measure milligrams per liter (mg/L) and micrograms per liter (ug/L) are equivalent to parts per million (ppm) and parts per billion (ppb), respectively. The units used to express conductivity are umhos/cm and are equivalent to microsiemens/cm (uS/cm). In addition, 1 meter (m) equals approximately 3.3 feet and 1 acre (ac) equals 4047 square meters (m^2).

RESULTS

Morphometry

Finger Lake is (61° 38'N, 149° 18'W) on the west side of the Matanuska River at an elevation of 103 m (Figure 1), and is not to be confused with the nearby Finger Lake described by Lebida (1983). Most recent morphometric data (Table 1) shows a surface area of 1.47×10^6 m^2, a mean lake depth of 4.7 m, a maximum depth of 13.4 m, and a total volume of 6.89×10^6 m^3 (5622 ac-ft). Lake inlets and outlets are ill defined or absent leading to the conclusion that groundwater is a major source for water renewal i.e., flushing (USFWS 1956). Finger Lake has 3 islands and a shoreline development of 2.91 (Figure 3).

Physical Characteristics

In-lake temperatures during August showed the formation of a distinct thermocline; however, as maximum epilimnetic temperatures cooled from 17.2 to 14.8°C between 17 and 30 August, the depth of the thermocline deepened from 4-6 m to 7-9 m, respectively (Figure 4A). Thus, the hypolimnion occurred at depths >6 m and comprised ~32% of the total lake volume. Euphotic zone depth equalled 1.6 m and the euphotic volume comprised ~34% of the total lake volume. In addition, Secchi disk transparency was observed to be 1.8 m (30 August).

Dissolved Gases

Dissolved oxygen (D.O.) concentrations ranged from 11.3-11.0 mg/L within the upper 4-m strata, but decreased rapidly within the thermocline and fell below 0.5 mg/L within the hypolimnion

Table 1. Historical data obtained from the literature (1953-1974) showing the variation in Finger Lake morphometric parameters.

Source	Surface area (acre)	Mean depth (feet)	Maximum lake depth (feet)	Total volume (acre-feet)
USFWS (1953)	343	15.0	53	4,984
ADF&G (1961)	437	14.7	--	6,405
ADF&G (1974)	362	15.5	44	5,622

FINGER LAKE

volume 6.9 X 10^6 m^3
surface area 1.5 X 10^6 m^2
mean depth 4.7m
maximum depth 13.4m

bottom contours in feet

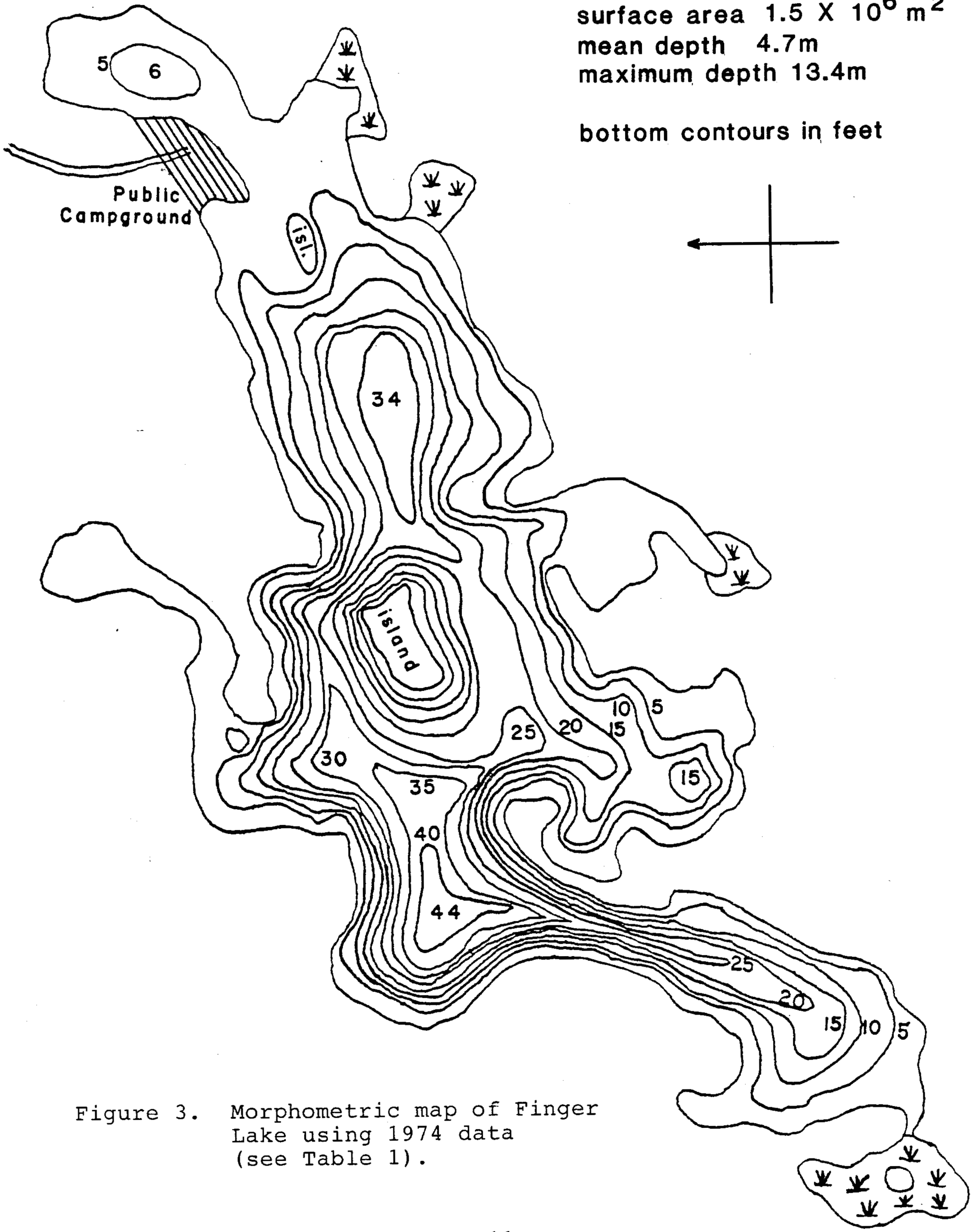

Figure 3. Morphometric map of Finger Lake using 1974 data (see Table 1).

(Figure 4B). Thus, while the epilimnion was well-oxygenated (aerobic) and, in fact, supersaturated with oxygen (~115%) on 18 August, the hypolimnion was without oxygen (anaerobic). In contrast, total sulfide (TS) concentrations remained <10.5 ug/L within the epilimnion, but increased dramatically within the hypolimnion and reached 144.2 ug/L near the bottom (Figure 4B). As the pH ranged from 8.0-8.3 units within the epilimnion, hydrogen sulfide (H_2S) was not detected; however, as the pH gradually decreased to 7.4 units within the hypolimnion the concentration of H_2S, increased to 44.7 ug/L (Figure 4C).

General Water Quality Parameters and Metals

Little difference was found between the 1-m and mid-epilimnetic samples (Table 2). In contrast, the hypolimnetic sample exhibited marked differences compared to the epilimnetic samples. The most obvious difference is a 40-fold increase in the concentration of total iron (1374 ug/L) within the hypolimnion compared to the epilimnion (35 ug/L); however, concentrations of calcium and magnesium were similar at all three depths sampled. In addition, conductivity was considerably higher; whereas, the pH was lower in the hypolimnion compared to the epilimnion. Laboratory conductivity values were comparable with insitu measurements from similar depths recorded 30 August (207, 209, and 256 umhos/cm respectively). Finally, turbidities were low, but were somewhat higher within the hypolimnion (5 NTU) compared to the epilimnion (1, 2 NTU); whereas, color showed no difference among the three samples and indicated a slight organic stain (13-16 Pt units).

Nutrient Levels

Reactive silicon levels were similar among the epilimnetic and hypolimnetic samples; however, we found substantial differences in nitrogen and phosphorus concentrations between the epilimnion

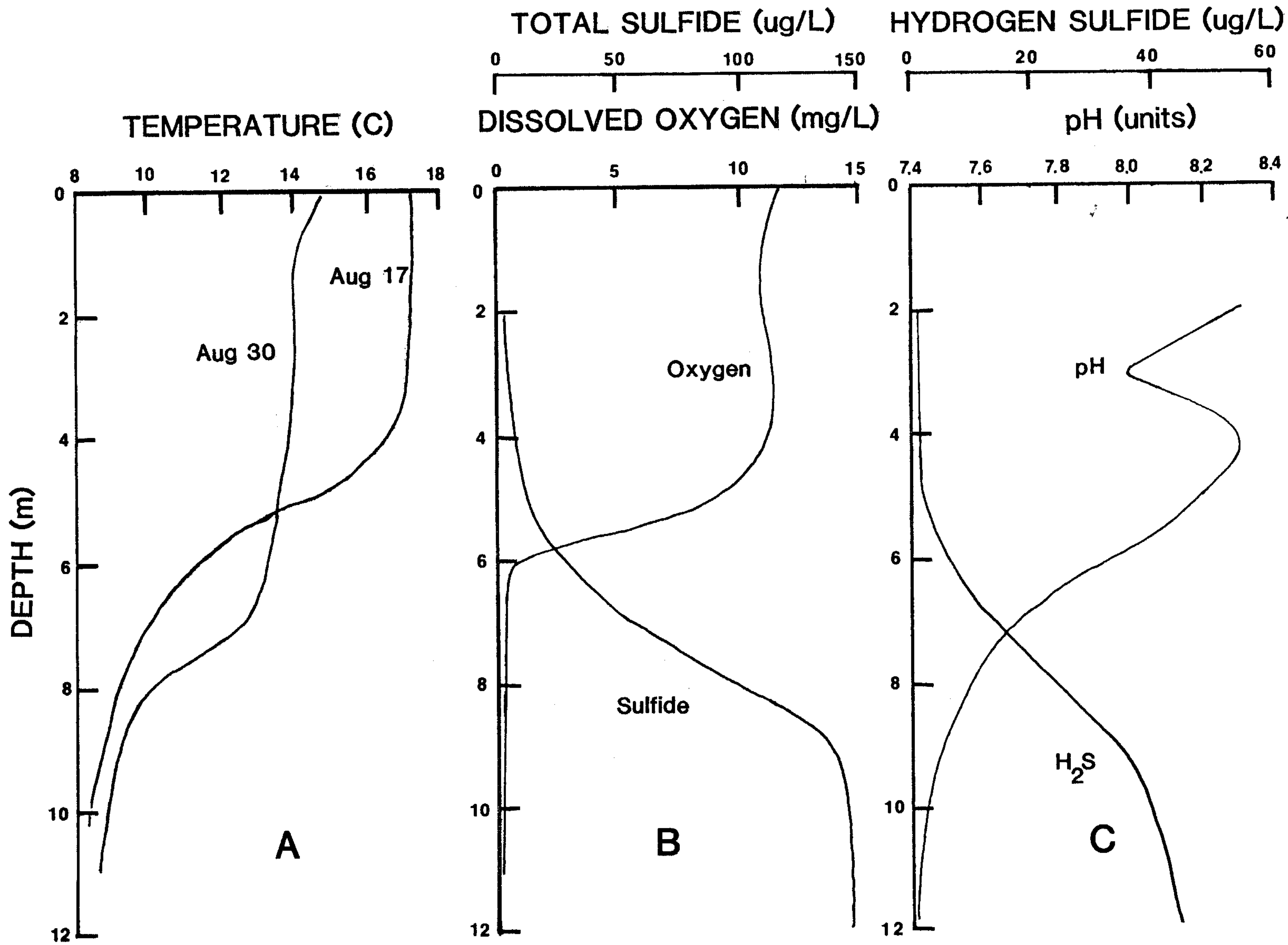

Figure 4. Temperature profiles for 17 August and 30 August 1988 for Finger Lake showing the changing depth of the thermocline (A); the decrease in dissolved oxygen and an increase in total sulfide gas concentration with increasing depth (B); and the decreasing pH and increasing toxic hydrogen sulfide levels with depth (C).

and hypolimnion (Table 3). The concentration of total ammonia (NH_3 + NH^+_4) within the hypolimnion was nearly 100 times higher (810 ug/L) compared to the epilimnion (9 ug/L). Because ammonia exists both as the unionized form NH_3 and the ammonium ion NH^+_4, the proportion of toxic NH_3 was calculated to be 0.3 ug/L and 21.5 ug/L within the epilimnion and hypolimnion, respectively. In contrast, nitrate (NO^-_3) + nitrite (NO^-_2) levels for all three samples were below detection limits (3.4 ug/L). Further, the total Kjeldahl nitrogen (TKN) concentration was ~38% higher (1266 ug/L) in the hypolimnetic sample compared to the epilimnetic samples (mean 917 ug/L). Finally, although organic nitrogen was not determined directly, values obtained by difference (i.e., TKN - total ammonia) were: 917, 897, and 456 ug/L for the 1-m, mid-epilimnetic and hypolimnetic samples, respectively.

We found little differences in reactive (inorganic), filterable and total phosphorus concentrations between the epilimnetic samples; however, concentrations were considerably higher in the hypolimnetic sample (Table 3). That is, filterable reactive phosphorus (FRP) levels were nearly 5-fold higher (15.0 ug/L), total filterable phosphorus (TFP) 2 times higher (16.0 ug/L), and total phosphorus (TP) levels were elevated (260.5 ug/L) within the hypolimnion compared to the epilimnion (mean 3.2, 7.3, and 44.2 ug/L, respectively). The total nitrogen to phosphorus (N:P) atom ratio was lower (11:1) but, inorganic N:P (IN:FRP) ratios higher (120:1) within the hypolimnion compared to the epilimnion (mean 47:1 and 9:1, respectively).

Phytoplankton and Chlorophyll a

The phytoplankton were dominated by the filamentous blue-green algae *Oscillatoria aghardhii* and *Lyngbya limnetica*. In addition, other species within the epilimnion in lesser abundance were *Anabaena circinalis* and *Merismopedia elegans* (Stockner, personal comm.). As a result, chl a levels within

Table 2. General water-quality parameters and metal concentrations obtained from three depths sampled within the deep basin of Finger Lake 17 August 1988.

Depth	Conductivity (umhos/cm)	pH (units)	Alkalinity (mg/L as $CaCO_3$)	Turbidity (NTU)	Color (Pt units)	Calcium (mg/L)	Magnesium (mg/L)	Iron (ug/L)
1 m	197	8.5	95	2.0	16.2	27.8	6.3	35
Mid-epilimnion	205	8.3	96	1.0	13.9	28.7	5.6	35
Mid-hypolimnion	238	7.3	107	5.0	12.8	33.1	6.3	1,374

Table 3. Nutrient concentrations and atom ratios, and algal pigments obtained from three depths sampled within the deep basin of Finger Lake 17 August 1988.

	Phosphorus (ug/L as P)			Nitrogen (ug/L as N)			Atom ratios		Reactive silicon	Chl *a*	Phaeo *a*
Depth	TP	TFP	FRP	TKN	Ammonia	$NO_3 + NO_2$	N:P	IN:FRP	(ug/L as Si)	(ug/L)	(ug/L)
1 m	40.9	7.7	2.7	926	9.0	<3.4	50:1	10:1	2,824	14.7	1.0
Mid-epilimnion	47.4	6.8	3.6	907	9.5	<3.4	46:1	8:1	2,788	16.7	1.9
Mid-hypolimnion	260.5	16.0	15.0	1,266	809.7	<3.4	11:1	120:1	3,202	1.7	12.7

the epilimnion were nearly 10 times (mean 15.7 ug/L) that determined for the hypolimnion (1.7 ug/L). In contrast, the concentration of the chl a degradation product (phaeophytin) was 10 times higher (12.7 ug/L) in the hypolimnion compared to the epilimnetic samples (mean 1.5 ug/L). Algal densities were highest and in 'bloom concentrations' within the mid-epilimnion compared to the 1-m strata; whereas, the hypolimnetic sample contained mostly phytodetritus.

Zooplankton

During mid-August 1988, the zooplankton community consisted of the macro-zooplankton species *Daphnia galeata mendotae, Cyclops* sp., and *Epishura nevadensis*. Respective densities (organisms/m^2) with corresponding mean body size (mm) were 35,000 (1.11), 11,000 (0.87), and 2000 (1.41). In addition to the macro-zooplankton, 3 types of rotifers were present: *Kellicottia* sp., *Asplanchia* sp., and *Keratella* sp.

Fecal Coliform Bacteria

Fecal coliform counts were <1 per 100 ml in samples collected from the deep basin, but no results were reported from the bottom samples (13 m) due to interference from high concentrations of suspended solids. In addition, counts were <1 per 100 ml in surface samples from sites 8 and 10; however, fecal coliform counts were 29, 106, and 13 per 100 ml near the surface at sites 9, 11, and 12, respectively (Figure 2).

DISCUSSION

Physical Characteristics

Finger Lake has long been a popular sportfishing and recreational resource for nearby Anchorage-Matsu Valley residents. As such, increased angler and residential use spawned early fishery enhancement efforts through lake stocking of coho salmon and rainbow trout (ADF&G 1956; ADF&G 1964; ADF&G 1966; ADF&G 1986). Despite interest in improving fishery stocks, consistent water quality data over the past 35 years are extremely sporadic. Nonetheless, previous lake studies have characterized Finger Lake as clearwater (USFWS 1953; USFWS 1956); and as having a high productivity potential based on littoral/total volume ratio (USFWS 1953) and morphoedaphic index (ADF&G 1974; ADF&G 1979; ADF&G 1986). In addition, hypolimnetic oxygen depletion has been documented beneath the ice during March and April (ADF&G 1960; ADF&G 1964; ADF&G 1965; ADF&G 1966; ADF&G 1967) and within the hypolimnion during thermal stratification (USFWS 1953; ADF&G 1963).

As in-lake temperature patterns influence all levels of production, as well as nutrient cycles and decomposition (Wetzel 1975), it is important to first understand the thermal structure of Finger Lake. Records indicating a well-defined thermocline occurring at ~6 m by early July (USFWS 1953) and continuing throughout August (ADF&G 1963) are consistent with the thermal structure exhibited by the temperature profiles in August 1988 (Figure 4A). As shallow lakes heat more rapidly following spring turnover compared to large lakes (Ruttner 1964), the morphometry of Finger Lake (Figure 3) would tend to favor a more prolonged period of summer stratification. Thus, as the thermocline (Figure 4A) prevents extended vertical mixing between the epilimnion and hypolimnion, dissolved oxygen levels within deep-lying strata may be depleted through aerobic respiration and decomposition by bacteria (Wetzel 1975). Indeed, by the middle of August the entire hypolimnion within Finger Lake was anaerobic (Figure 4B).

Hypolimnetic Oxygen Depletion and Anaerobic Decomposition

Oxygen depletion within the hypolimnion and a well-established thermocline (Figure 4A) also allows the concentrations of metabolites produced from anaerobic decomposition to accumulate. It is known that under anaerobic conditions concentrations of total iron, ammonia and total sulfide can increase (Wetzel 1975). In August 1988, we found total iron concentrations within the epilimnion comparable to the levels found under conditions of chemical equilibria in naturally occurring waters (Stumm and Lee 1960). However, under the reduced environment of the hypolimnion high concentrations of ferrous iron were apparently released into solution from the bottom sediments (Stumm and Lee 1960; Koenings 1976). As a result, iron levels within the hypolimnion of Finger Lake were very high (Table 2).

Anaerobic decomposition can also produce hydrogen sulfide (H_2S) which exists in equilibrium with the non-toxic dissociated ion HS^- as a function of pH (Hutchinson 1957). That is, the proportion of H_2S increases with decreasing pH (Figure 4C), and the levels of H_2S observed within the hypolimnion (44.7 ug/L) exceed the 2.0 ug/L considered safe to fish and other aquatic life (Smith et al. 1979). Ammonia is also a primary decomposition product which is readily oxidized under aerobic conditions by bacteria to nitrite and nitrate nitrogen (nitrification). In contrast, under anaerobic conditions nitrification does not occur and total ammonia concentrations increase (Wetzel 1975). Total ammonia levels above 1000 ug/L (Haywood 1983) are considered unsafe, under prolonged exposure, to aquatic life. Moreover, total ammonia consists of both unionized NH_3 and as the ammonium ion (NH^+_4). The proportion of each species is a function of pH and temperature. The proportion of NH_3 increases with increasing temperature and pH, and is considered toxic to salmonids and other aquatic life at concentrations at or above 16 ug/L (Haywood 1983). Thus, although total ammonia levels in Finger Lake (Table 3) were slightly below 1000 ug/L (809.7 ug/L), concentrations of NH_3 (21.5 ug/L) were slightly above allowable or safe levels.

Despite the ammonia (NH_3) and sulfide (H_2S) gases within the hypolimnion of Finger Lake (Figure 4B and C), adverse effects to fish and other aquatic life are confined to ~30% of the total lake volume. During winter, anaerobic conditions may occur throughout the lake if large summer algal blooms are not completely decomposed prior to freeze-over. Dissolved oxygen levels (<5.0 ug/L) below standards acceptable for salmonids (Davis et al. 1979) have been previously reported beneath the ice in Finger Lake at depths as shallow as 3 m (ADF&G 1965; ADF&G 1967). However, ground water renewal may be sufficient to prevent complete deoxygenation of the lake during the winter.

Another effect of anaerobic decomposition is an increase in inorganic phosphorus (FRP) released from the lake-bottom sediments (Wetzel 1975). In addition, as anaerobic decomposition is also less efficient compared to aerobic decomposition, organic phosphorus levels increase as algal cells within the epilimnion die, sink, and subsequently accumulate within the hypolimnion. These processes are evident in Finger Lake as both FRP and total phosphorus (TP) concentrations along with phytodetritus and turbidities are significantly higher within the hypolimnion compared to the epilimnion (Table 3). Moreover, epilimnetic TP levels in Finger Lake are the highest found by the limnology laboratory for similar nonturbid (clear and organically stained) lakes in Alaska (Figure 5).

Algal Production

In nonturbid lakes phosphorus levels are correlated to chl a, an index of algal biomass (Sakamoto 1966; Dillon and Rigler 1974; Vollenweider 1976; and Prepas and Trew 1983). This relationship is also evident in Alaska lakes i.e; increasing phosphorus levels are accompanied by an increase in chl a

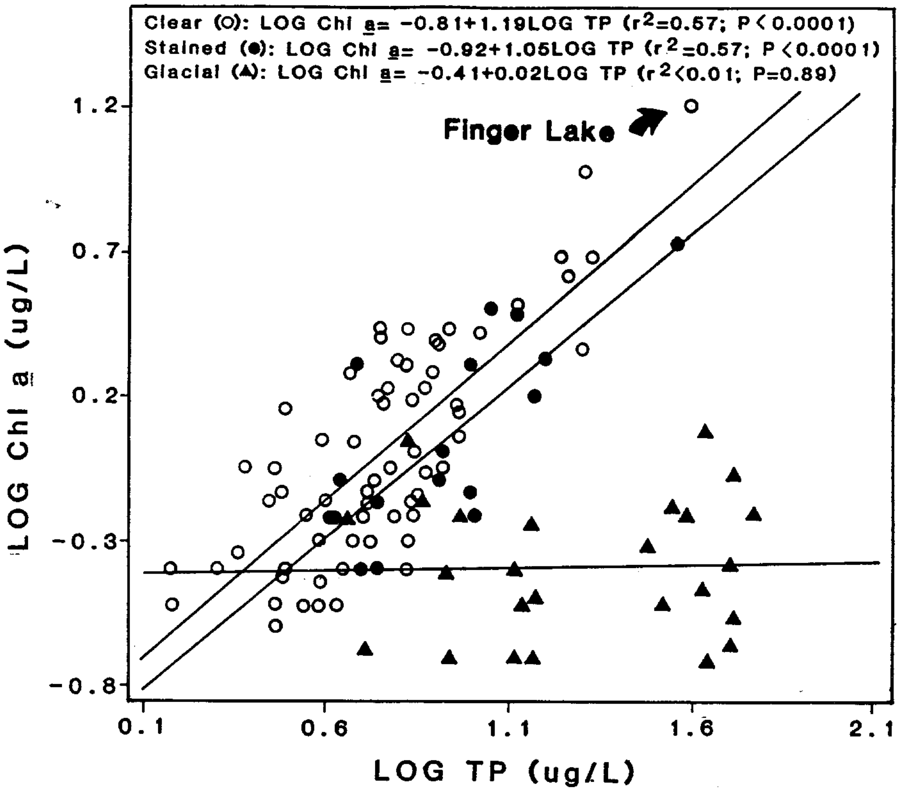

Figure 5. Finger Lake epilimnetic phosphorus-chlorophyll a (P-C) levels obtained 17 August 1988 relative to the Alaskan P-C relationship stratified by lake type (i.e., clear, stained, and glacial).

(Figure 5). Chl a levels in Finger Lake were consistent with the Alaskan phosphorus-chl a relationship and were one of the highest found among lakes surveyed since 1979 by the ADF&G limnology program (Figure 5). In contrast, chl a levels within the hypolimnion were very low as algal pigments were degraded into inactive phaeophytin (Table 3). Similarly, the blue-green algae *Oscillatoria agardhii* and *Lyngbya limnetica* were most conspicuous within the mid-epilimnion and in bloom densities; whereas, the hypolimnion contained primarily dead algal cells. In addition, blue-green algae, under low concentrations of inorganic nitrogen (ammonia, nitrite, and nitrate) tend to out-compete more desirable green algae which are favored under higher N:P ratios (Wetzel 1975). Blue-green algae are also commonly associated with changes in the taste and odor of lake water, and *Oscillatoria* sp. and *Lyngbya* sp. are considered polluted water algae (APHA 1985).

Algal cell densities (chl a) within nonturbid lakes are inversely correlated with light penetration as measured by Secchi disk (SD) transparency (Carlson 1977; Lorenzen 1980). That is, high algal densities reduce SD transparency. The low SD transparency (1.8 m) observed in Finger Lake during August is consistent with SD-chl a models, but differed considerably from SD transparencies of 4.1 and 4.3 m observed within the same area of the lake (i.e. the deep basin) during the summer of 1952 (USFWS 1953).

Historical Versus Current Water Quality

It must be stressed that we lack definitive historical diagnostic water-quality data, and the samples we do have are few and inconsistent. In addition, analytical methodologies have changed over time. Given these constraints, it appears Finger Lake may have undergone some changes in light penetration, phytoplankton and zooplankton community structures over time (Table 4). In contrast, it also appears general water

Table 4. Comparison of Finger Lake phytoplankton (A) and zooplankton (B) community composition on 7 July 1952 to 17 August 1988. Species are indicated as present (P) or not present (NP).

A. Phytoplankton

Oscillatoria agardhii 1952	*Oscillatoria agardhii* 1988	*Lyngbya limnetica* 1952	*Lyngbya limnetica* 1988	*Anabaena circinalis* 1952	*Anabaena circinalis* 1988	*Merismopedia elegans* 1952	*Merismopedia elegans* 1988
NP	P	NP	P	NP	P	NP	P

B. Zooplankton

Daphnia galeata mendotae 1952	*Daphnia galeata mendotae* 1988	*Epishura nevadensis* 1952	*Epishura nevadensis* 1988	*Cyclops* sp. 1952	*Cyclops* sp. 1988	*Bosmina* sp. 1952	*Bosmina* sp. 1988	*Alonella* sp. 1952	*Alonella* sp. 1988
NP	P	NP	P	NP	P	P	NP	P	NP

Table 5. Comparison of general water-quality parameters and metal concentrations obtained 17 August 1988 to historical values derived from the epilimnion of the deep basin in Finger Lake.

Conductivity (umhos/cm)		Alkalinity (mg/L $CaCO_3$)		Calcium (mg/L)		Magnesium (mg/L)		Secchi disk (m)		Hypolimnetic dissolved oxygen (mg/L)	
1973	1988	1952	1988	1973	1988	1973	1988	1952	1988	1952	1988
206	197	84	95	31.0	27.8	4.9	6.3	4.3	1.8	0.5	<0.5

quality parameters e.g. conductivity, alkalinity, pH, calcium and magnesium, as well as hypolimnetic oxygen depletion are comparable between 1952 and the present (Table 5). In addition, there is no historic record of winter fish kills nor the presence of hydrogen sulfide which is easily detected by its characteristic 'rotten egg odor'. Thus, the degree of historical change is difficult to ascertain. Nonetheless, during the summer of 1988 low water renewal coupled with warm spring temperatures and long sunny days combined with sufficient nutrients to produce algal blooms.

The current (August 1988) high TP and chl a levels, low inorganic nitrogen concentrations, decreased light penetration, and hypolimnetic oxygen depletion with concomitant hydrogen sulfide and ammonia evolution are certainly symptomatic of a highly eutrophic lake. In addition, lake eutrophication is a naturally occurring process, but it can be accelerated through watershed changes (Dillon and Rigler 1975) which have been documented for Finger Lake. Indeed, residential development around the lake has increased, particularly during the 1970's. Although insufficient data exists to determine the extent of nutrient loading, if any, derived from septic or other domestic sources; residential wastewater has been found to contain 11 and 4 grams of nitrogen and phosphorus, respectively, per capita per day (Schmidt et al. 1980). The high soil permeability and ground water flow rates around Finger Lake could augment nutrient loading from such cultural sources (Tschobanoglous 1987). Finally, it should be noted that the eutrophic conditions found in Finger Lake are not unique as the early stages are evident (Woods 1986) in nearby Big Lake (Figure 1).

Recommendations

1. Conduct limnological surveys more frequently throughout the summer growing season (~4 sample trips) to fully document baseline water quality. In addition, Finger Lake should be sampled at least once during the mid-winter ice cover to determine the possibility of winter fish kills due to low oxygen levels.

2. Determine the hydrologic budget of Finger Lake i.e., groundwater flow rates and lake water renewal time.

3. Verify lake morphometry as these characteristics have shown considerable variation over the past 30 years.

4. Determine the sources of phosphorus loading into Finger Lake as a first step in designing any remedial actions.

ACKNOWLEDGEMENTS

The authors wish to express their appreciation to Larry Engel, Durand Cook, Gary Liepitz and Al Havens (ADF&G) for assisting with the field work. The authors also thank Richard Barrett (DEC) for providing the methodology on fecal coliform bacteria, and Ginny Petanovitch for the preparation of figures. In addition, the authors express thanks to personnel of the Matanuska-Susitna Borough, Tax Assessors office for their assistance in documenting lake residential occupancy. Finally, we gratefully acknowledge the limnology and DEC laboratory staff for the timely analysis of samples.

REFERENCES

Alaska Department of Fish and Game, Sport Fish Division. 1960. Federal Aid in Fish Restoration, Annual Report of Progress, 1959-60. Proj. F5R1 142 p.

Alaska Department of Fish and Game, Sport Fish Division. 1963. Federal Aid in Fish Restoration, Annual Report of Progress, 1962-63. Proj. F5R4 505 p.

Alaska Department of Fish and Game, Sport Fish Division. 1964. Federal Aid in Fish Restoration, Annual Report of Progress, 1963-64. Proj. F5R5 368 p.

Alaska Department of Fish and Game, Sport Fish Division. 1965. Federal Aid in Fish Restoration, Annual Report of Progress 1964-65. Proj. F5R6. 356 p.

Alaska Department of Fish and Game, Sport Fish Division. 1966. Federal Aid in Fish Restoration, Annual Report of Progress 1965-66. Proj. F5R7. 269 p.

Alaska Department of Fish and Game, Sport Fish Division. 1967. Federal Aid in Fish Restoration, Annual Report of Progress 1966-67. Proj. F5R8. 271 p.

Alaska Department of Fish and Game, Sport Fish Division. 1974. Federal Aid in Fish Restoration, Annual Report of Performance 1973-74. Proj. F96 15.

Alaska Department of Fish and Game, Sport Fish Division. 1979. Federal Aid in Fish Restoration, Annual Report of Performance 1978-79. Proj. F911 20.

Alaska Department of Fish and Game, Sport Fish Division. 1986. Federal Aid in Fish Restoration and Anadromous Fish Studies, Annual Performance Report, 1985-86. Proj. F918 27.

American Public Health Association (APHA), American Water Works Association and Water Pollution Control Federation. 1985. Standard methods for the examination of water and wastewater. 16th ed. New York, N.Y. 1268 p.

Brooks, J. L. 1957. The systematics of North American *Daphnia*. Mem. Conn. Acad. Arts Sci. 13:1-180.

Carlson, R. E. 1977. A trophic state index for lakes. Limnol. Oceanogr. 22: 361-369.

Crowther, J., B. Wright, and W. Wright. 1980. Semi-automated determination of total phosphorus and total Kjeldahl nitrogen in surface waters. Anal. Chem. 119:313-321.

Davis, J. C., G. I. Bresnick, P. Doudoroff, T.R. Doyle, A.J. Mearns, J. B. Pearce, J. J. Peterka, J. G. Robinson, and D. L. Swanson. 1979. Dissolved Oxygen. 169-174. In: A Review of the EPA Redbook: Quality criteria for water. R. V. Thurston, R. C. Russo, C. M. Felleroff, Jr., T. A. Edsall, and Y. M. Barber, Jr. (eds.) Water Quality Section, American Fisheries Society, Bethesda, MD.

Dillon, P. J. and F. H. Rigler. 1974. The phosphorus-chlorophyll a relationship in lakes. Limnol. Oceanogr. 19: 767-773.

Dillon, P. J. and F. H. Rigler. 1975. A simple method for predicting the capacity of a lake for development based on lake trophic status. J. Fish. Res. Board Can. 32:1519-1531.

Eisenreich, S. J., R. T. Bannerman, and D. E. Armstrong. 1975. A simplified phosphorus analysis technique. Environ. Letters 9: 43-53.

Emerson, K., R. C. Russo, R. E. Lund, and R. V. Thurston. 1975. Aqueous ammonia equilibria calculations: effect of pH and temperature. J. Fish. Res. Bd. of Canada 32: 2379-2383.

Golterman, H. L. 1969. Methods for chemical analysis of fresh water. IBP Handbook 8. Blackwell Scientific Publications, Oxford. 166 p.

Haywood, G. P. 1983. Ammonia toxicity in teleosts fishes: a review. Can. Tech. Rep. Fish. Aquat. Sci. No. 1177. 35p.

Hutchinson , G. E. 1957. A treatise on limnology, Vol. I, geography, physics, and chemistry. New York: John Wiley & Sons. 1115 p.

Koenings, J. P. and F. F. Hooper. 1976. The influence of colloidal organic matter on iron and iron-phosphorus cycling in an acid bog lake. Limnol. Oceanogr. 21: 684-696.

Koenings, J. P. , J. A. Edmundson, G. B. Kyle, and J. M. Edmundson. 1987. Limnology field and laboratory manual: methods for assessing aquatic production. Alaska Department of Fish and Game, FRED Division Report Series 71: 221 p.

Lebida, R. C. 1983. Upper Cook Inlet salmon habitat evaluation, 1979-1981. Alaska Department of Fish and Game, FRED Division Report Series 8: 73 p.

Lorenzen, M. W. 1980. Use of chlorophyll-Secchi disk relationships. Limnol. Oceanogr. 25: 371-372.

Pennak, R. W. 1978. Fresh-water invertebrates of the United States, 2nd edition. John Wiley and Sons. New York. 803 p.

Prepas, E. E., and D. O. Trew. 1983. Evaluation of the phosphorus-chlorophyll relationship for lakes off the Precambrian Shield in western Canada. Can. J. Fish. Aquat. Sci. 40: 27-35.

Reimann, B. 1978. Carotenoid interference in the spectrophotometric determination of chlorophyll degradations products from natural populations of phytoplankton. Limnol. Oceanogr. 23: 1059-1066.

Ruttner, F. 1964. Fundamentals of limnology. University of Toronto Press, Canada. 295 p.

Sakamoto, M. 1966. Primary production by phytoplankton community in some Japanese lakes and its dependence on lake depth. Arch. Hydrobiol. 62: 1-28.

Schindler, D. W. 1971. Light, temperature, and oxygen regimes of selected lakes in the experimental lakes area, Northwestern Ontario. J. Fish. Res. Board. Can. 28:157-169.

Schmidt, C. J. and W. C. Boyle. 1980. Design manual-onsite wastewater treatment disposal systems. U. S. Environmental Protection Agency, EPA 625/1-80-012. Washington, D. C. 120:58 p.

Smith, L. L., Jr., S. J. Broderius, C. L. Ho, A. J. Mearns, and J. B. Pearce. 1979. Sulfide-hydrogen sulfide. p. 272-276. In: A review of the EPA Redbook: Quality criteria for water. R. V. Thurston, R. C. Russo, C. M. Felleroff, Jr., T. A. Edsall, and Y. M. Barber, Jr. (eds.) Water Quality Section, American Fisheries Society, Bethesda, MD. 313 p.

Stainton, M. P., M. J. Capel, and F. A. J. Armstrong. 1977. The chemical analysis of fresh water. Can. Spec. Publ. No. 25, 2nd ed. 180 p.

Strickland, J. D. H. and T. R. Parsons. 1972. A practical handbook of seawater analysis. Bull. Fish. Res. Bd. of Canada. 167:310 p.

Stumm, W. and G. F. Lee. 1960. The chemistry of aqueous iron. Schweizererische Zeitschrift fur Hydrologie Revue Suisse d-Hydrologic. 22:295-319.

Tchobanaglous, G. and E. Schroeder. 1985. Water quality. Addison-Wesley Pub. California. 184 p.

U. S. Fish and Wildlife Service and Alaska Game Commission. 1953. Quarterly report. Federal Aid in Fish Restoration. Proj. F1R2. Vol. 3. Rpt. 3.

U. S. Fish and Wildlife Service and Alaska Game Commission. 1956. Quarterly report. Federal Aid in Fish Restoration. Proj. F1R5 Vol. 5. Rpt. 3 and 5.

Vollenweider, R. A. 1976. Advances in defining critical loading levels for phosphorus in lake eutrophication. Mem. Ist. Ital. Idrobiol. 33:53-83.

Wetzel, R. G. 1975. Limnology. W. B. Saunders Co., Philadelphia. 743 p.

Wilson, M. S. 1959. Calanoida. P. 738-794. In: W. T. Edmondson [ed.], Fresh-water biology, 2nd. ed. John Wiley and Sons, New York.

Woods, P. F. 1986. Deep-lying chlorophyll maxima at Big Lake: implications for trophic state classification of Alaskan lakes. p. 195-200. In: D. L. Kane [ed.], Proceedings: Cold Regions Hydrology Symposium. American Water Resources Assoc. Bethesda, MD.

Yeatman, H. C. 1959. Cyclopoida. p. 795-815. In: W. T. Edmondson [ed.], Fresh-water biology, 2nd. ed. John Wiley and Sons, New York.