Some physical and chemical features of saline lakes in central British Columbia

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A series of 33 lakes in central British Columbia were studied to characterize them chemically. The lakes are similar morphometrically, but differ considerably in their ionic concentrations and compositions. Dissolved solids range from 27 to 147 100 ppm with average seasonal values > 3 000 ppm in 17 of the lakes. Magnesium sulphate and sodium carbonate-type lakes predominate at higher salinities, while sodium bicarbonate-carbonate and mixtures of magnesium, sodium, sulphate, bicarbonate, and carbonate predominate at lower salinities. Chloride is always present, but usually at low concentrations. All the lakes are athalassic alkaline lakes.

Significant seasonal and vertical variation occurs in total ionic concentrations and relative ionic compositions of the lakes. Chemical and thermal stratification occurs in those lakes deeper than 3–4 m or with conductivities > 5 000 micromhos. Seasonal variation in total ionic concentration occurs in shallow polymictic lakes and in the surface waters of chemically stratified lakes. Clinograde oxygen profiles occur during summer in the stratified lakes, anærobiosis is present in the monimolimnions of meromictic lakes and winter oxygen depletion is characteristic of all but the largest of the lakes.

Using 11 of their physicochemical properties, a graded series of 13 different types may be distinguished from the 33 lakes by the unweighted pair group method of cluster analysis.

KEY INDEX WORDS: *British Columbia, physicochemical properties, saline lakes.*

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Introduction

Various aspects of the flora and fauna of saline lakes in central British Columbia have been studied on the assumption that the extreme environmental gradients characteristic of saline lakes might result in more conspicuous faunal and floral adaptations (Blinn, 1969; Cannings, 1973; Scudder, 1969*a*, *b*; Scudder and Mann, 1968; Scudder *et al.*, 1972; Topping, 1971 and 1975; Topping and Acton, 1976). However, the physicochemical properties of only a few of these lakes have been considered in detail (Blinn, 1971; Cummings, 1940; Northcote and Halsey, 1969), although Scudder (1969*a*, *b*) has reported certain features characteristic of all the lakes.

The survey reported herein was undertaken to characterize the chemical composition of these lakes, to determine seasonal concentrations of the major ions and to help develop a rationale of classifying lakes according to their physicochemical properties to facilitate interpretations of floral and faunal patterns.

Study area

The lakes occur in five areas in south-central British Columbia (Fig. 1) at elevations of 700 m in the southwest to 1 100 m in the northwest (Table I). Chilcotin (Riske Creek), Springhouse, and Gang Ranch areas (Figs. 1A, 1B, and 1C) are located on the Fraser Plateau in the Fraser River Drainage,[2] whereas Clinton and Kamloops areas (Figs. 1D and 1E) are

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[2] Since this study was done, the Chilcotin area has been remapped and official names assigned to some of the lakes. New names of the lakes, followed in parentheses by old names used in Scudder (1969*a*, *b*) and Topping (1971) are Barnes L. (Box 4), Barkley L. (Near Opposite Box 4), East L. (Racetrack), Lake Greer (Box 89), Lake Jackson (Opposite Box 4), Lake Lye (Box 20–21), and Round-Up L. (Phalarope). In addition, GR2 is Goodenough L., a lake which already has been mapped and about which information has been published (Hutchinson, 1957).

Miocene and Pliocene olivine basalt, whereas the southeastern half (i.e., Thompson Plateau) is underlain by a diversity of rock formations, including sedimentary and volcanic formations of Palæozoic age which have been intruded by granitic rock and flat or gently dipping early Tertiary (Eocene) lavas (Holland, 1964).

Weather in the South West Interior Plateau Climatic Region is characterized by low precipitation (annual mean 340.2 mm) with 61 per cent in the summer six months (May to October). The mean daily temperature is 2.3 C for the year, and ranges from —11.6 C in January to 13.7 C in July (Atmospheric Environment Service, 1975).

Vegetation within the region is typically open grassland with mixed stands of conifers and aspen (Munro, 1945; Munro and Cowan, 1947), although south of Six Mile Lake and around Kamloops it tends to be more dry forest or sage brush. Except for Six Mile Lake, the lakes are located on open grassland or at its interface with forest.

Although the exact origins of each of the lake basins are not known, most of the lakes are depressions in fluted and grooved rolling glacial till plain and usefully can be described as ponds.

Occurrence of Pleistocene glaciation means the lakes can be no older than 10 000 years. Temperatures in the Pacific Northwest were higher and precipitation was lower 4 000–6 000 years ago (Hansen, 1947) and probably most, if not all of the lakes, have had a discontinuous existence since then. Certainly, some of the lakes (e.g., Westwick L.) were dry or nearly dry during the 1930's (Munro, 1945) and again in the 1950's.

The lakes were selected to approximate the range of ionic concentrations of water bodies in the area. However, lakes with higher ionic concentrations (Blinn, 1971; Scudder, 1969*a*, *b*), as well as many with lower ionic concentrations also are known from the area (Northcote and Larkin, 1956; Scudder and Mann, 1968). Thus, the series cannot be considered a random sample of all lakes in the area. No conscious bias was used to select lakes with particular ionic compositions and the series may be considered representative. Of the 33 lakes, 17 are saline (i.e., dissolved solids > 3 000 ppm) according to the criteria of Williams (1966). The lakes are athalassic in their ionic compositions.

Methods

Lake areas were determined planimetrically from low-level aerial photographs. Depth soundings taken along transects with a 200 kHz/sec Furuno echo sounder were used to construct bathymetric maps of each lake. Volumes, mean depths, and volume development ratios were calculated from the maps. Drainage areas were estimated from topographic maps.

Water samples were collected from 30 lakes during spring and summer and four of these lakes were also sampled during winter. Three other lakes (Six Mile, Sorenson L., and GR3) were sampled only once. Samples were collected with a 2-litre van Dorn bottle from successive metre intervals beginning at the surface, and were stored frozen in polyethylene bottles until ready for use and then maintained at 4 C. During winter, ice samples also were collected for analysis.

Temperature profiles were measured with a YSI thermister telethermometer to ±0.1 C and pH was measured to ±0.03 with an expanding scale Radiometer PHM 26 pH meter. Conductivities of undiluted samples were determined with a line operated Radiometer CD 2 conductivity meter; values obtained were then corrected to the standard reference temperature of 25 C. Dissolved oxygen was determined by the unmodified Winkler method. While some effervescence and loss of iodine occurred upon acidification of samples with conductivities > 5 000 micromhos, subsequent oxygen determinations in these lakes using the Miller method (Walker *et al.*, 1970) have given much the same values (Reynolds 1974).

Total dissolved solids (TDS) were determined by evaporation at 105 C of water filtered through 0.45 micron Millipore membranes and weighing the salt residues to ±0.1 mg. Sodium and potassium were determined by flame emission photometry, using a Zeiss PF5 flame photometer, the potassium values being determined with a sodium and calcium chloride swamp solution so as to provide a constant background; alternative methods for the determination of sodium and potassium were not available in our laboratory at the time of analyses. Calcium and magnesium were determined (jointly) by the EDTA-versonate method (Richards, 1954). Calcium was determined independently by fluorometry (Wallach and Steck, 1963) using a Turner Model III fluorometer; magnesium values were then obtained by subtraction. Carbonate and bicarbonate were determined potentiometrically using 0.02 N HC1 as titrant, according to Standard Methods (American Public Health Association, 1960). Chloride was determined by amperometric titration using a Cotlove chloridometer, while sulphate was determined by the ion exchange method (Mackereth, 1955). Hydrogen sulphide was estimated by effervescing water onto paper treated with lead and comparing the resultant colour to a commercially prepared colour chart (Hach Chemicals, Ames, Iowa). Appropriate dilutions of the samples were made for determination of potassium, sodium, and sulphate.

Organic carbon content of bottom muds collected during October 1969 was determined by the method of Walkley (Richards, 1954). Composition of these muds also was evaluated by wet-sieving portions of each sample. The muds were separated into silt and very fine sand (0.15 mm), fine and medium sand (0.15–0.42 mm), medium and coarse sand (0.42–0.59 mm), coarse sand (0.59–0.83 mm), coarse and very coarse sand (0.83–1.98 mm), and granules ($>$1.98 mm). Each fraction was measured as the percentage of the dry weight of the total sample sieved.

Temperature, pH, dissolved oxygen, carbonate, and bicarbonate were determined immediately in the field, while the remaining analyses were performed as soon as possible. Most samples were analysed completely within four months.

The general accuracy of the majority of the chemical methods employed has been listed by Angino *et al.* (1965). Concentrations of total anions and cations for 261 samples analysed agreed within 4.59 ± 0.52 per cent (mean ± standard error) according to procedures outlined in Standard Methods (American Public Health Association, 1960).

Results

Physicochemical Properties

Morphometric properties of the lakes (Table I) differed considerably with areas ranging from 0.86 to 127.68 ha, volumes from 5 100 to 6 416 400 m^3, and maximum depths from 1.5 to 15.5 m. Volume development ratios indicate most of the basins are relatively 'saucer shaped'. Since 1964, Long E., LE 1, and LE 2 have been one continuous water body. Lake Lye consists of east and west basins separated by a sill less than 1 m deep. Bathymetric maps of the lakes are given in Topping (1969).

Analyses of major ionic constituents and certain other properties are given in Table II. Those properties, with the exception of hydrogen sulphide, were analysed by analysis of variance using a three-way fixed effects model without replication and Duncan's New Multiple Range test to determine significant differences in their seasonal patterns of vertical distribution both between and within the lakes. Unless otherwise indicated, the level of significance used in these interpretations was $P<0.01$. Substratum composition and organic carbon content of the bottom muds are given in Tables III and IV respectively.

Ionic Concentration

Prior to chemical analysis of water samples, ionic concentration was measured as a function of electrical conductivity (k_{25}) and total dissolved solids (TDS). Subsequently, conductivity was found to be a significant linear function of TDS and a significant curvilinear function of total ion content (Fig. 2). However, analysis of covariance indicates two linear equations are required to describe the relation between conductivity and TDS (i.e., one for magnesium sulphate-type lakes and one for the other types of lakes). The range of ionic compositions and concentrations measured suggests the relationships shown in Figure 2 generally should be applicable to lakes throughout the region.

TABLE I

Geographic features and morphometric properties of lakes in central British Columbia

Lake	Altitude (m)	Drainage Area (ha)	Surface Area (ha)	Volume ($m^3 \times 10^3$)	z_m (m)	$\bar{z}$ (m)	$\bar{z}/z_m$
Clinton	988	—	—	—	—	—	—
Goodenough L.	1 095	29	15.37	127.3	1.5	0.8	0.53
LB 2	899	24	3.06	65.6	2.5	1.1	0.44
LB 1	884	16	5.11	150.4	5.2	2.9	0.56
Long L.	1 037	1 309	33.53	735.5	4.5	2.2	0.49
Barnes L.	945	61	17.19	348.4	4.5	2.0	0.44
Bower's L.	701	12	3.55	46.1	2.5	1.3	0.52
LE 1	1 037	40	2.19	22.1	2.3	1.0	0.43
LE 2	1 037	211	4.80	44.7	2.3	0.9	0.39
Round-Up L.	945	67	30.84	787.6	6.2	2.6	0.40
Lake Lye	945	131	46.52	1 283.2	5.4	2.8	0.52
White L.	1 037	10 221	127.68	6 416.4	15.5	5.0	0.32
LE 5	1 037	22	2.19	4.9	0.7	0.2	0.29
Boitano L.	975	559	80.68	2 202.2	4.5	2.7	0.60
Rush	975	126	19.60	212.7	2.5	1.1	0.41
LE 3	1 037	39	3.13	22.0	1.5	0.7	0.47
LE 4	1 037	64	6.99	88.8	1.5	1.3	0.84
Six Mile	988	—	—	—	15.0	—	—
Barkley L.	945	40	5.81	79.9	2.3	1.4	0.61
Lake Greer	945	32	15.17	156.8	2.3	1.0	0.44
Rock L.	945	111	34.64	387.5	2.5	1.1	0.44
Nr. Phalarope	945	13	5.06	64.6	3.0	1.3	0.43
Westwick L.	945	535	58.30	728.3	4.5	1.3	0.29
GR 3	1 095	—	—	—	—	—	—
Sorenson L.	945	292	23.30	—	2.5	—	—
Lac du Bois	869	111	29.63	1 380.2	8.3	3.9	0.47
Nr. Op. Cres.	945	46	6.88	99.2	3.3	1.4	0.42
Box 17	945	13	2.65	31.4	3.3	1.1	0.33
L. Jackson	945	39	4.55	32.8	2.2	0.7	0.32
East L.	945	172	27.05	503.0	6.5	1.9	0.29
Sp 6	975	15	0.86	5.1	1.5	0.6	0.40
Box 27	945	32	4.30	23.0	1.5	0.5	0.33

TABLE II
Physicochemical properties of saline lakes in central British Columbia

									MILLIEQUIVALENTS PER LITER							
LAKE	DATE	DEPTH (m)	TEMP (°C)	k_{25} (µmhos)	TDS (mg/l)	pH	O_2 (cc/l)	H_2S (mg/l)	Na	K	Ca	Mg	CO_3	HCO_3	Cl	SO_4
CLINTON	22/ 5/66	0	----	----	141,351	----	----	---	375.0	16.21	2.28	1,352.0	----	----	24.27	1,543.0
	5/ 8/66	0	----	55,932	147,100	8.10	----	---	327.5	18.8	1.16	1,630.0	0.0	52.70	31.25	2,043.0
GOODENOUGH L.	20/ 5/66	0	15.6	30,100	27,626	10.05	----	---	525.0	11.22	0.54	2.42	379.0	57.10	116.2	0.0
		1	25.9	34,900	33,556	10.20	----	---	550.0	13.08	0.72	2.45	473.6	54.30	141.1	0.0
	4/ 8/66	0	21.1	40,000	39,207	10.20	----	0.0	705.0	13.90	0.14	3.90	560.6	72.20	166.1	0.0
		1	20.6	40,508	42,128	10.20	----	0.0	725.0	13.80	0.14	3.90	573.6	68.00	164.8	0.0
	16/ 2/67	Ice	----	39,930	42,100	9.90	----	---	585.0	10.50	0.29	3.13	718.4	274.60	126.5	0.0
		0	-2.0	57,320	69,248	9.70	----	---	1,312.0	25.00	0.29	9.41	978.0	162.00	296.0	0.0
LB 2	23/ 5/66	0	15.6	13,400	11,912	9.50	5.05	---	200.0	8.00	0.76	4.30	57.10	51.10	13.97	59.78
		1	14.4	16,600	15,249	9.50	3.91	---	230.0	10.50	0.76	5.25	66.00	71.50	17.56	75.04
		2	11.7	17,900	17,154	9.45	4.35	---	223.0	10.41	0.40	6.02	84.40	67.30	19.62	84.06
	6/ 8/66	0	22.8	17,119	15,256	9.20	3.84	0.0	228.8	9.50	1.00	5.40	66.00	60.60	15.39	96.48
		1	22.2	17,034	15,292	9.20	3.72	0.0	221.8	8.90	0.44	5.70	64.30	61.60	15.71	100.84
		2	21.1	17,034	15,412	9.25	2.13	0.0	225.0	8.70	0.44	5.60	68.00	58.90	15.97	102.28
LB 1	23/ 5/66	0	14.7	11,700	16,714	8.80	5.70	---	62.5	6.79	2.12	150.3	4.30	8.00	6.52	196.9
		1	14.7	13,780	19,135	8.70	6.14	---	65.0	7.62	2.04	174.7	4.30	8.30	7.21	228.4
		2	17.0	14,420	24,174	8.65	4.13	---	67.5	8.50	1.98	196.1	4.60	9.20	8.25	252.2
		3	17.0	20,590	37,016	8.40	3.15	---	107.0	11.90	2.84	319.2	2.10	11.70	11.19	410.4
		4	18.6	34,150	66,592	7.60	0.0	---	193.0	19.10	11.40	616.0	0.00	27.30	19.91	889.2
		5	16.4	39,800	87,828	7.15	0.0	---	253.0	24.50	14.10	794.6	0.00	69.60	7.82*	1,040.0
	6/ 8/66	0	27.6	14,746	23,056	8.70	5.32	0.0	77.5	8.60	1.18	194.9	4.00	9.80	8.27	265.0
		1	26.7	14,746	22,584	8.70	5.32	0.0	76.3	9.10	1.20	189.5	3.50	10.20	8.24	239.0
		2	25.6	14,746	22,716	8.60	5.15	0.0	76.8	9.00	1.34	190.2	3.50	10.30	8.58	274.9
		3	24.4	14,915	22,760	8.60	8.01	0.0	76.8	9.10	1.50	192.0	3.40	10.40	8.10	284.4
		4	25.3	37,119	73,876	7.80	5.60	4.5	212.5	24.80	6.24	662.1	0.00	38.60	20.48	983.7
		5	25.3	35,932	72,656	7.80	5.94	5.0	200.0	24.50	6.10	638.5	0.00	38.50	16.83*	817.0
LONG L.	20/ 5/66	0	14.4	9,110	7,792	9.00	5.87	---	102.5	7.30	0.66	10.94	21.40	35.20	14.51	67.12
		1	14.4	9,260	8,006	9.05	6.04	---	102.5	7.33	0.60	11.00	20.80	25.70	14.98	70.12
		2	13.1	16,410	15,537	9.40	6.04	---	210.0	12.35	0.62	15.33	43.60	37.90	28.95	129.6
		3	10.6	17,280	16,673	9.40	4.28	---	220.0	13.20	0.76	15.37	45.10	41.50	30.89	130.5
		4	7.8	24,180	24,157	9.40	0.0	---	409.0	17.92	0.66	10.29	68.60	57.10	45.39	166.0
	3/ 8/66	0	22.2	11,525	10,452	9.20	5.60	0.0	140.0	8.10	0.10	13.80	23.80	31.40	18.50	100.6
		1	22.0	11,525	10,100	9.20	5.43	0.0	125.0	7.50	0.10	13.80	24.00	31.40	18.77	76.28
		2	20.9	11,695	10,248	9.30	4.48	0.0	126.5	7.70	0.10	13.80	25.60	31.00	19.18	78.72
		3	19.4	19,492	18,440	9.35	0.73	0.0	225.5	13.70	0.18	14.70	48.50	42.40	34.88	137.8
		4	15.3	23,729	25,636	9.45	0.0	5.0	319.0	18.70	0.16	14.60	70.60	54.80	48.76	196.1
	17/ 2/67	Ice	----	2,494	2,036	8.90	----	---	24.17	1.00	0.13	2.77	4.92	6.24	3.20	20.75
		0	0.0	12,033	11,660	8.80	----	---	150.0	8.75	0.47	17.85	26.00	49.50	23.00	45.96
		1	0.0	12,033	11,811	8.90	----	---	150.0	8.65	0.60	18.04	27.84	49.06	22.24	25.10
		2	0.2	12,361	11,890	9.00	----	---	149.5	8.75	0.44	16.86	27.60	44.90	22.60	21.46
		3	0.4	12,690	12,070	9.05	----	---	160.0	8.90	0.40	16.40	29.76	42.44	22.23	20.18
		4	1.3	23,740	25,026	9.25	----	---	342.5	17.99	0.40	14.34	73.60	55.20	45.60	46.51
BARNES L.	13/ 5/66	0	11.4	6,610	5,283	9.40	----	---	70.00	7.90	0.62	1.41	22.10	36.70	21.90	10.33
		1	12.2	11,510	9,430	9.40	----	---	120.0	12.79	0.76	2.57	25.60	54.60	36.40	20.15
		2	12.8	13,780	12,082	9.40	----	---	175.0	17.15	0.76	3.36	52.80	61.70	45.70	36.45
		3	8.3	14,900	12,893	9.20	----	---	180.0	18.05	0.76	2.79	56.00	65.50	49.00	32.75
	28/ 7/66	0	20.0	11,017	8,599	9.30	----	0.0	119.3	11.90	0.14	3.10	35.60	45.10	32.78	21.10
		1	20.0	11,017	8,872	9.30	----	0.0	117.5	11.90	0.14	3.10	36.00	56.90	33.86	26.60
		2	14.4	13,051	10,797	9.30	----	5.0	139.8	14.10	0.10	3.60	45.60	53.20	40.26	30.00
		3	8.6	16,102	13,712	9.40	----	5.0	173.5	17.90	0.08	3.30	61.90	65.80	50.73	39.00
		4	5.6	17,966	15,441	9.40	----	5.0	206.3	20.50	0.06	2.80	74.60	70.90	55.15	46.00
BOWER'S L.	24/ 5/66	0	14.4	9,820	13,842	8.20	7.93	---	55.00	5.50	31.40	98.65	0.00	3.70	6.95	158.8
		1	13.9	10,390	13,961	8.15	8.25	---	52.50	5.50	28.00	99.00	0.00	3.50	7.01	158.4
	7/ 8/66	0	22.0	11,864	17,636	8.60	----	0.0	64.00	6.00	27.20	119.7	0.96	1.40	7.00	193.4
		1	22.0	11,864	17,148	8.60	----	0.0	63.80	5.80	22.00	124.4	0.96	1.20	7.35	200.6
LE 1	20/ 5/66	0	13.3	8,960	7,889	9.25	5.54	---	102.5	6.95	0.72	11.26	20.00	25.30	17.12	91.00
		1	13.6	9,270	8,214	9.00	5.54	---	110.0	7.38	0.72	11.43	21.76	26.20	16.59	60.25
	3/ 8/66	0	22.5	11,271	9,370	9.30	4.87	0.0	120.0	7.43	0.18	13.80	24.16	24.03	18.84	75.30
		1	22.8	11,186	9,928	9.40	4.65	0.0	118.8	7.20	0.18	13.84	24.16	23.77	18.61	68.81
LE 2	20/ 5/66	0	12.5	7,080	5,979	8.95	5.71	---	75.00	5.42	0.76	12.73	14.60	25.01	11.14	32.96
		1	12.8	8,840	7,675	8.95	4.87	---	97.5	6.62	0.62	11.45	18.40	26.25	14.19	46.59
	3/ 8/66	0	22.2	11,017	9,627	9.30	5.15	0.0	116.0	7.05	0.14	13.88	24.00	28.96	18.16	76.79
		1	22.0	11,102	9,482	9.30	0.00	0.0	117.5	7.10	0.14	13.86	24.16	29.28	21.32	69.95
ROUND-UP L.	12/ 5/66	0	12.2	4,380	3,164	9.20	----	---	45.00	2.92	0.32	2.14	8.90	18.40	15.24	6.61
		1	11.7	4,340	3,146	9.15	----	---	41.25	3.30	0.46	1.99	8.20	19.10	15.27	6.49
		2	5.6	7,840	6,167	9.20	----	---	90.00	6.51	0.66	3.62	16.90	35.70	28.68	12.05
		3	3.3	8,490	6,751	9.20	----	---	96.25	7.00	0.60	3.95	16.80	39.10	31.27	11.37
		4	3.3	8,640	7,157	9.10	----	---	103.75	7.62	0.40	3.72	23.00	40.30	32.50	17.30
	27/ 7/66	0	18.9	6,814	5,185	9.15	5.26	0.0	71.50	4.70	0.60	3.10	15.00	30.50	24.50	10.80
		1	17.8	6,864	5,362	9.15	5.26	0.0	71.50	5.00	0.68	3.00	14.20	31.70	24.91	12.70
		2	17.0	6,881	5,336	9.15	4.65	0.0	70.00	4.90	0.68	3.00	14.40	31.10	24.91	13.60
		3	14.4	7,797	6,113	9.10	0.50	3.5	80.90	5.90	0.84	3.30	17.60	30.80	28.98	14.80
		4	8.9	8,814	6,953	9.15	0.00	5.0	91.90	6.40	0.74	3.40	20.00	40.30	32.50	17.30

TABLE II—*Continued*

LAKE	DATE	DEPTH (m)	TEMP (°C)	k_{25} (umhos)	TDS (mg/l)	pH	O_2 (cc/l)	H_2S (mg/l)	MILLIEQUIVALENTS PER LITER							
									Na	K	Ca	Mg	CO_3	HCO_3	Cl	SO_4
LAKE LYE (EAST BASIN)	13/ 5/66	0	13.0	4,680	3,207	9.10	5.88	---	47.50	3.78	0.60	2.29	10.30	24.00	14.81	8.09
		1	13.3	4,680	3,300	9.10	5.94	---	48.75	3.69	0.60	2.20	10.20	23.90	15.15	2.04
		2	10.3	6,750	4,987	9.10	4.71	---	58.75	5.40	0.72	3.32	16.20	35.70	22.90	3.88
		3	6.7	7,490	5,810	9.10	3.02	---	83.75	6.45	0.86	3.63	17.90	40.50	24.70	8.70
		4	4.4	8,830	7,053	9.20	0.00	---	105.0	8.00	0.66	3.13	25.80	49.00	31.20	10.56
		5	4.2	11,310	10,012	9.20	0.00	---	137.5	9.60	0.72	1.41	37.90	59.00	41.10	13.46
	27/ 7/66	0	20.0	6,220	4,713	9.10	4.70	0.0	64.80	4.30	0.70	3.00	14.40	32.10	20.55	8.04
		1	19.7	6,220	4,674	9.10	4.59	0.0	65.50	4.20	0.70	3.00	15.70	31.70	20.63	5.01
		2	17.8	6,237	4,711	9.10	4.09	0.0	64.60	4.40	0.84	2.90	13.40	33.00	21.05	7.99
		3	15.0	6,610	4,947	9.10	2.30	3.5	70.00	5.00	0.86	3.10	14.90	34.70	22.43	7.46
		4	7.8	7,542	5,732	9.10	0.00	5.0	80.60	5.80	0.80	3.20	19.20	39.20	26.15	9.68
		5	6.4	8,644	6,902	9.20	0.00	5.0	92.00	6.50	----	----	23.40	44.60	30.15	13.36
LAKF LYE (WEST BASIN)	13/ 5/66	0	13.6	4,720	3,322	9.00	5.50	---	51.25	3.78	0.66	2.23	10.72	24.59	15.62	12.29
		1	13.6	4,545	3,224	9.10	5.94	---	48.75	3.82	0.72	2.12	10.88	23.61	15.26	6.91
		2	8.9	7,210	5.711	9.10	4.43	---	82.50	5.60	0.72	3.64	17.04	29.55	24.15	10.47
		3	5.3	7,230	5,414	9.10	3.34	---	80.00	6.28	0.92	3.48	16.80	40.40	25.45	7.65
		4	4.4	8,700	6,840	9.10	0.00	---	101.3	7.82	0.92	3.17	22.56	48.05	32.52	7.86
		5	4.4	11,310	9,620	9.20	0.00	---	136.3	9.99	0.68	1.08	36.44	62.00	41.79	8.53
	27/ 7/66	0	19.2	6,237	4,716	9.15	4.70	0.0	66.90	4.40	0.68	2.64	13.92	32.72	20.52	4.40
		1	19.4	6,237	4,601	9.20	4.59	0.0	62.90	4.50	0.68	3.05	14.40	32.16	20.86	5.90
		2	17.2	6,254	4,721	9.20	4.09	0.0	62.60	4.50	0.68	3.07	13.92	32.72	20.11	7.20
		3	15.0	6,576	4,984	9.20	2.30	3.5	66.30	4.80	0.68	3.26	15.84	33.68	21.48	5.29
		4	7.8	8,644	6,770	9.20	0.00	5.0	85.60	6.60	0.74	3.30	21.28	46.48	28.80	0.44
		5	6.4	9,831	8,054	9.20	0.00	5.0	97.30	7.50	----	----	27.84	50.80	32.63	6.02
WHITE L.	21/ 5/66	0	11.1	5,090	3,966	9.10	5.65	---	55.00	5.32	0.20	9.44	26.60	33.70	8.38	7.89
		1	11.7	5,210	3,981	9.20	5.71	---	55.00	5.32	0.12	9.45	26.10	33.90	7.07	1.82
		2	11.7	5,090	3,986	9.20	5.82	---	57.50	5.29	0.32	9.30	26.00	34.10	8.20	5.75
		3	11.7	5,060	3,993	9.20	5.71	---	57.50	5.13	0.20	9.32	25.90	34.30	8.07	0.92
		4	11.7	5,130	4,012	9.30	5.71	---	52.50	5.13	0.12	9.41	27.80	32.90	8.51	13.23
		5	10.6	5,260	4,143	9.20	5.27	---	58.25	5.47	0.20	9.51	28.40	34.30	8.38	4.52
		6	8.3	5,560	4,433	9.30	3.40	---	59.00	5.78	0.12	9.80	28.80	37.10	8.77	0.00
		7	7.2	5,560	4,361	9.25	3.29	---	59.00	5.78	0.16	9.86	29.40	37.10	8.90	0.85
		8	6.7	5,710	4,518	9.30	2.08	---	57.50	6.38	0.26	9.90	31.20	37.00	9.09	0.00
		9	5.8	6,210	4,926	9.30	0.00	---	65.00	7.22	0.20	9.80	34.00	40.20	10.25	0.00
		10	5.6	6,670	5,351	9.30	0.00	---	75.00	7.15	0.26	9.29	36.60	43.70	11.30	0.00
		11	5.6	7,700	6,306	9.30	0.00	---	77.50	6.96	0.26	9.29	36.90	43.90	11.26	0.00
		12	5.6	6,950	5,558	9.30	0.00	---	82.50	7.72	0.76	8.66	39.90	44.60	11.83	0.00
		13	5.6	7,70	6,306	9.30	0.00	---	97.50	7.72	0.50	8.73	40.60	58.80	13.82	0.00
		14	5.6	8,680	7,120	9.20	0.00	---	97.50	9.10	0.46	8.57	42.40	72.70	15.04	0.00
		15	5.6	8,300	7,150	9.20	0.00	---	97.00	8.65	0.90	5.83	40.20	70.40	14.60	0.00
	4/ 8/66	0	20.3	5,068	3,937	9.25	8.96	0.0	57.50	4.10	0.18	9.90	28.60	31.60	8.18	11.90
		1	20.3	5,085	4,281	9.25	8.96	0.0	57.00	4.10	0.18	9.90	28.60	31.60	8.54	4.86
		2	20.3	5,085	4,233	9.35	9.07	0.0	57.50	4.00	0.10	9.90	28.20	31.70	8.18	0.00
		3	20.0	5,085	4,121	9.35	8.74	0.0	57.00	4.80	0.20	9.80	29.30	30.80	8.13	0.08
		4	17.8	5,085	4,157	9.35	8.06	0.0	56.80	4.00	0.14	9.80	29.40	30.90	8.74	2.20
		5	16.7	5,085	4,177	9.35	5.60	0.0	59.50	4.20	0.10	9.80	29.04	31.60	8.16	0.00
		6	15.9	5,119	4,280	9.35	4.06	0.0	57.50	4.20	0.16	9.60	29.10	32.20	8.35	0.00
		7	13.9	5,254	4,365	9.35	1.74	0.0	60.00	4.20	0.14	9.30	30.40	32.40	8.80	0.00
		8	10.3	5,661	4,728	9.35	0.00	3.5	67.00	4.70	0.16	9.80	33.00	34.90	9.50	0.00
		9	8.9	5,780	4,793	9.40	0.00	5.0	67.50	4.70	0.30	9.70	33.10	35.90	9.46	0.00
		10	7.8	6,119	5,093	9.40	0.00	5.0	71.00	5.10	0.14	9.60	35.00	37.70	11.38	0.00
		11	6.7	6,695	5,666	9.40	0.00	5.0	77.50	5.60	0.18	9.30	40.00	40.70	11.28	0.00
		12	6.4	6,864	5,933	9.40	0.00	5.0	81.30	5.90	0.14	9.40	40.80	43.10	12.10	0.00
		13	6.1	7,475	6,354	9.35	0.00	5.0	90.50	6.30	0.16	9.20	44.60	51.00	15.42	0.00
		14	5.9	8,390	6,888	9.40	0.00	5.0	99.30	7.00	0.21	8.80	41.60	59.10	15.49	0.00
		15	5.6	8,390	7,559	9.40	0.00	5.0	102.3	7.10	0.18	8.70	49.40	53.70	14.85	0.25
	15/ 2/67	Ice	----	1,619	1,148	9.10	----	---	15.00	1.18	0.15	3.30	9.60	8.80	2.76	0.00
		0	0.0	5,360	4,300	9.10	3.42	---	56.50	4.32	0.17	10.17	29.76	37.30	8.76	0.00
		1	0.0	5,360	4,273	9.20	3.38	---	52.00	4.50	0.17	10.19	29.36	37.64	8.77	0.31
		2	0.0	5,360	4,354	9.25	3.44	---	52.00	4.50	0.17	10.14	29.44	37.46	8.77	0.00
		3	0.0	5,306	4,359	9.25	3.46	---	52.00	4.50	0.18	10.14	29.28	37.42	8.63	0.00
		4	0.0	5,306	4,746	9.25	3.29	---	52.00	4.50	0.18	10.04	29.12	37.78	8.65	0.00
		5	0.0	5,316	4,399	9.25	3.00	---	57.50	4.37	0.18	10.08	29.12	37.58	8.75	0.00
		6	0.0	5,316	4,285	9.25	2.49	---	56.50	4.47	0.18	10.08	29.92	39.08	9.94	0.67
		7	0.0	5,338	4,295	9.25	1.37	---	52.00	4.57	0.18	10.08	29.36	37.64	9.60	0.15
		8	0.3	5,272	4,349	9.25	0.00	---	56.50	4.55	0.18	10.06	28.88	37.62	9.09	0.00
		9	0.7	5,316	4,359	9.25	0.00	---	56.50	4.75	0.33	10.07	29.28	37.32	9.38	0.00
		10	1.0	6,104	4,969	9.25	0.00	---	63.75	5.25	0.30	9.27	37.00	35.00	10.82	0.00
		11	1.5	5,864	4,861	9.25	0.00	---	63.75	5.13	0.52	9.24	32.84	41.56	10.59	0.00
		12	3.5	6,269	5,193	9.25	0.00	---	68.75	5.38	0.19	9.25	36.00	44.00	11.65	0.00
		13	4.0	7,187	5,940	9.20	0.00	---	76.25	6.20	0.19	9.07	36.80	52.10	12.57	0.00
		14	4.0	7,187	6,439	9.15	0.00	---	82.50	6.38	0.22	8.78	38.80	55.90	15.00	0.00
LE 5	22/ 5/66	0	12.0	3,870	3,058	8.40	6.59	---	40.00	3.09	0.72	12.28	2.44	40.30	7.23	6.08
	5/ 8/66	0	20.0	4,136	3,185	8.70	3.30	0.0	38.30	3.18	0.30	11.79	5.76	38.12	7.53	2.45
BOITANO L.	10/ 5/66	0	14.4	3,905	3,105	9.00	4.95	---	34.50	2.92	0.86	11.08	5.00	17.70	4.25	22.74
		1	13.3	3,850	3,051	9.00	4.90	---	34.00	2.96	0.76	11.07	5.10	17.40	4.08	29.17
		2	13.3	3,850	2,958	9.00	4.90	---	34.00	3.00	0.66	11.23	5.10	17.70	4.11	18.71
		3	13.3	3,790	3,070	8.95	4.68	---	33.50	3.07	0.72	11.19	4.80	17.70	4.25	18.43
		4	11.7	4,035	3,095	8.90	4.68	---	35.00	2.81	0.86	11.17	5.00	17.80	5.17	20.59
		5	8.9	4,190	3,210	8.80	0.00	---	38.50	3.15	0.72	12.39	3.90	21.40	4.45	17.63
	26/ 7/66	0	18.9	4,119	3,223	8.85	4.14	0.0	33.80	3.20	0.80	11.70	5.10	17.40	4.61	22.60
		1	18.9	4,102	3,220	8.85	4.09	0.0	33.30	3.40	0.70	11.90	5.10	17.60	4.72	23.10
		2	17.8	4,119	3,193	8.85	4.26	0.0	33.80	3.50	0.76	11.90	5.00	18.50	4.74	22.90
		3	17.8	4,136	3,161	8.90	3.98	0.0	33.80	3.60	0.68	11.90	5.30	18.20	4.83	23.70
		4	17.2	4,136	3,142	8.85	3.86	0.0	34.10	3.50	0.68	12.00	4.80	18.60	4.70	23.10
		5	17.0	4,203	3,234	8.70	0.00	0.00	34.30	3.30	0.68	12.20	4.20	21.00	4.80	24.00

TABLE II—*Continued*

LAKE	DATE	DEPTH (m)	TEMP (°C)	k_{25} (umhos)	TDS (mg/l)	pH	O_2 (cc/l)	H_2S (mg/l)	MILLIEQUIVALENTS PER LITER							
									Na	K	Ca	Mg	CO_3	HCO_3	Cl	SO_4
RUSH	11/ 5/66	0	15.3	3,550	3,773	8.70	4.50	---	30.00	2.32	0.74	10.60	3.00	17.00	3.65	16.86
		1	15.0	3,490	3,715	8.70	4.65	---	30.50	2.32	0.76	10.66	3.10	16.90	3.90	16.00
		2	15.3	3,960	3,113	8.50	0.00	---	43.50	2.55	0.80	12,96	2.40	21.40	4.38	19.76
	31/ 7/66	0	20.0	4,254	3,208	8.60	3.53	0.0	34.40	3.10	0.64	12.80	4.00	19.90	4.86	23.80
		1	18.3	4,254	3,280	8.60	4.00	0.0	35.10	3.00	0.76	13.00	3.70	20.20	4.51	24.01
		2	17.8	4,254	3,309	8.60	3.92	0.1	35.30	3.00	0.80	12.70	3.50	20.40	4.59	24.92
LE 3	22/ 5/66	0	11.7	3,435	2,709	8.50	5.49	---	30.00	2.62	0.90	13.87	4.40	27.25	5.16	5.91
	5/ 8/66	0	19.7	3,915	3,237	9.20	7.17	0.0	35.30	2.75	0.24	13.49	15.84	24.48	6.86	6.50
LE 4	22/ 5/66	0	13.1	3,100	2,498	8.70	6.47	---	27.50	2.36	0.72	11.96	3.52	31.00	5.08	0.00
		1	12.8	3,210	2,470	8.70	6.36	---	27.50	2.41	0.76	11.92	----	----	5.26	6.19
	5/ 8/66	0	20.3	3,864	3,117	9.20	8.90	0.0	35.30	2.58	0.24	12.71	14.40	26.16	6.65	3.80
		1	20.3	3,864	3,262	9.20	8.46	0.5	35.30	2.70	0.44	12.43	14.24	25.48	6.65	2.45
SIX MILE	17/ 5/66	0	----	2,899	2,612	8.00	----	---	5.41	0.33	8.56	26.34	----	3.85	0.53	31.02
BARKLEY L.	14/ 5/66	0	12.8	2,264	1,955	8.90	5.85	---	13.75	1.42	1.86	12.42	1.60	4.80	2.90	23.09
		1	12.8	2,320	1,939	8.90	5.74	---	13.75	1.50	1.62	12.72	1.80	4.70	2.78	21.55
		2	12.2	2,830	2,961	8.70	5.53	---	20.75	1.83	2.28	19.25	1.80	7.80	4.15	26.00
		3	7.8	3,660	3,379	8.60	1.92	---	24.00	2.25	2.78	22.03	1.60	8.80	4.73	32.02
	28/ 7/66	0	20.9	3,136	2,782	9.00	8.06	0.0	17.00	1.40	1.08	18.70	2.70	6.20	3.92	25.90
		1	20.9	3,169	2,978	8.80	8.23	0.0	16.90	1.60	1.02	18.80	2.30	6.60	3.94	24.40
		2	17.8	3,186	3,024	8.80	5.10	0.0	17.10	1.60	1.00	19.00	2.10	6.80	3.95	25.40
		3	15.9	3,390	3,163	8.65	0.00	5.0	18.50	1.50	1.26	20.20	1.80	8.10	4.22	28.70
LAKE GREER	17/ 5/66	0	13.3	1,525	1,096	8.39	6.16	---	13.25	1.74	0.86	2.53	0.32	13.70	1.27	2.19
		1	13.0	1,490	1,059	8.60	6.22	---	13.25	1.69	0.76	2.59	0.96	12.60	1.28	3.53
		2	11.1	1,510	1,125	8.58	6.05	---	13.28	1.74	0.80	2.50	0.96	12.60	1.13	1.93
	29/ 7/66	0	19.2	1,695	1,329	8.70	4.42	0.0	14.30	1.50	0.28	3.30	2.40	12.70	0.98	4.52
		1	18.9	1,695	1,387	8.80	4.12	0.0	14.20	1.30	0.32	3.30	2.60	12.40	1.01	2.84
		2	19.2	1,695	1,375	8.80	0.90	1.0	14.50	1.30	0.30	3.30	2.40	12.50	1.04	3.15
ROCK	17/ 5/66	0	12.6	1,395	1,049	8.80	6.39	---	14.25	1.08	0.84	1.47	3.10	13.00	2.23	0.00
		1	12.2	1,415	1,053	8.90	6.34	---	14.00	0.94	0.84	1.47	3.20	12.90	1.59	0.00
		2	11.7	1,395	1,057	8.90	6.32	---	14.25	1.12	0.96	1.41	3.40	12.70	1.52	0.34
		0	20.3	1,593	1,184	9.00	4.14	0.0	15.80	0.99	0.38	2.00	5.40	11.80	1.26	0.01
		1	20.3	1,585	1,249	9.10	3.15	0.0	15.80	0.93	0.36	2.00	5.50	11.80	1.30	0.45
		2	18.3	1,585	1,119	9.10	2.86	0.1	15.80	0.92	0.46	1.90	5.50	11.60	1.28	1.12
GR 3	10/ 9/66	0	----	1,500	1,241	8.90	----	---	12.99	0.95	1.52	6.28	1.07	12.62	0.61	1.95
SORENSON L.	4/ 5/67	0	----	1,500	1,031	8.90	----	---	4.43	0.69	1.15	11.95	1.33	6.38	0.34	9.29
NR PHALAROPE	12/ 5/66	0	14.4	1,170	867	8.60	5.57	---	7.25	1.38	0.92	5.19	1.30	11.70	0.41	3.61
		1	14.4	1,189	853	8.60	4.86	---	7.25	1.23	0.96	5.17	1.50	12.20	0.42	0.00
		2	14.4	1,189	873	8.60	4.44	---	7.25	1.31	0.90	5.28	1.40	12.30	0.86	0.00
	27/ 7/66	0	18.9	1,492	865	8.10	1.04	0.0	9.00	1.70	0.84	6.30	0.00	16.90	1.02	0.00
		1	17.8	1,475	854	8.15	1.23	0.0	8.75	1.50	0.94	6.30	0.00	16.60	1.06	0.00
		2	16.4	1,492	850	8.10	1.18	0.0	8.75	1.60	0.94	6.30	0.00	16.70	1.26	0.30
WESTWICK L.	10/ 5/66	0	15.6	1,208	948	8.90	3.60	---	4.63	0.79	1.26	11.06	1.20	7.40	0.10	7.82
		1	15.6	1,282	1,170	8.90	3.67	---	4.63	0.86	1.36	11.12	1.20	7.10	0.12	6.47
		2	15.6	1,189	1,159	8.90	3.63	---	4.48	0.86	1.22	11.28	2.30	6.20	0.05	8.84
		3	15.6	1,189	1,066	8.90	3.31	---	4.88	0.79	1.22	11.22	2.30	6.80	0.21	4.54
	26/ 7/66	0	23.3	1,356	969	8.80	1.96	0.0	4.59	0.88	0.70	11.30	1.90	8.20	0.34	6.59
		1	21.1	1,322	918	8.75	1.68	0.0	4.78	0.82	0.76	11.30	1.90	8.20	0.34	8.47
		2	19.4	1,339	901	8.80	0.22	0.0	4.73	0.85	0.76	11.30	2.10	8.00	0.42	5.44
	?/12/66	0	----	1,130	1,026	9.40	----	---	4.54	0.62	0.40	7.34	3.80	2.98	0.11	8.33
	?/ 1/67	0	----	1,559	1,395	9.05	----	---	6.25	0.88	0.51	13.15	3.20	5.25	0.12	9.76
	18/ 2/67	Ice	----	428	292	9.30	----	---	1.41	0.13	0.49	3.23	3.10	2.00	0.08	1.63
		0	0.9	1,770	1,479	8.10	----	---	6.38	0.90	1.42	15.14	0.00	9.42	0.16	4.88
		1	2.7	1,770	1,255	8.05	1.02	---	6.38	0.90	1.44	15.14	0.00	9.42	0.13	10.70
		2	3.6	1,770	1,447	7.90	0.20	---	6.25	0.90	2.31	14.19	0.00	9.30	0.13	10.08
LAC DU BOIS	23/ 5/66	0	14.4	944	765	8.50	6.95	---	2.50	0.71	1.30	8.56	0.80	11.30	0.18	0.00
		1	13.9	944	761	8.50	6.78	---	2.50	0.67	1.76	8.18	1.52	10.00	0.17	0.00
		2	13.3	732	718	8.65	7.06	---	2.50	0.67	1.92	8.00	1.60	9.90	0.25	1.90
		3	12.2	948	724	8.60	6.41	---	3.25	0.67	1.84	8.10	1.60	9.90	0.17	1.10
		4	11.1	919	727	8.50	6.08	---	3.00	0.75	1.76	8.20	1.52	10.00	0.20	0.43
		5	10.0	948	782	8.70	3.91	---	3.00	0.67	1.54	8.42	1.60	9.90	0.12	1.87
		6	9.2	948	760	8.80	1.58	---	3.00	0.75	1.64	8.30	1.60	10.00	0.21	1.01
		7	8.6	925	756	8.70	0.60	---	3.50	0.75	1.60	8.32	1.60	9.80	0.18	1.05
		8	7.8	1,094	842	8.14	0.43	---	3.50	0.71	2.32	8.55	0.00	11.61	0.26	0.21
	6/ 8/66	0	22.2	966	859	8.60	5.35	0.0	2.50	0.48	0.92	9.80	1.80	9.10	0.27	1.44
		1	22.2	966	764	8.80	5.29	0.0	2.40	0.53	0.92	9.30	1.90	9.00	1.06	0.73
		2	21.1	966	777	8.80	5.26	0.0	2.35	0.45	0.96	9.20	1.90	8.90	0.43	0.80
		3	20.9	949	819	8.75	4.82	0.0	2.37	0.55	0.92	9.20	1.90	8.80	0.22	1.20
		4	20.3	966	746	8.75	3.70	0.0	2.38	0.58	1.02	9.10	1.70	9.00	0.21	1.39
		5	17.8	966	738	8.75	1.37	0.0	2.35	0.53	1.02	9.10	1.70	9.00	0.19	1.02
		6	13.9	975	753	8.45	0.00	5.0	2.35	0.63	0.96	9.10	1.20	9.70	0.19	1.37
		7	11.7	1,008	776	8.20	0.00	5.0	2.34	0.78	1.32	8.80	0.00	10.90	0.16	1.56
		8	10.0	1,025	826	8.20	0.00	4.0	2.35	0.75	1.32	9.00	0.00	11.10	0.27	1.42

TABLE II—*Continued*

LAKE	DATE	DEPTH (m)	TEMP (°C)	k_{25} (umhos)	TDS (mg/l)	pH	O_2 (cc/l)	H_2S (mg/l)	MILLIEQUIVALENTS PER LITER							
									Na	K	Ca	Mg	CO_3	HCO_3	Cl	SO_4
NR OF CRES	16/ 5/66	0	11.7	1,048	569	8.60	5.48	---	3.40	0.67	1.46	3.82	0.72	6.40	0.30	1.20
		1	11.7	730	541	8.60	5.85	---	3.45	0.64	1.34	3.92	0.64	6.40	0.21	1.05
		2	11.7	722	571	8.70	5.85	---	3.35	0.64	1.30	3.96	0.88	6.30	0.24	0.92
		3	11.1	798	561	8.70	5.64	---	3.35	0.64	1.22	4.00	0.80	6.30	0.20	0.96
	29/ 7/66	0	18.9	781	654	8.60	0.92	0.0	3.33	0.56	0.56	4.90	0.88	6.70	0.45	1.90
		1	18.6	783	630	8.55	0.34	0.0	3.33	0.54	0.58	4.90	0.96	6.60	0.45	1.30
		2	17.5	780	634	8.60	0.22	0.3	3.35	0.54	0.58	4.90	1.60	6.00	0.45	1.70
		3	15.9	788	623	8.70	0.00	5.0	3.31	0.57	0.56	5.00	1.12	6.60	0.43	1.60
BOX 17	16/ 5/66	0	12.8	733	472	8.30	6.38	---	3.25	0.67	1.06	4.33	0.00	8.90	0.13	0.23
		1	12.5	734	466	8.30	6.81	---	3.35	0.75	1.10	4.35	0.00	8.90	0.13	0.00
		2	12.2	733	485	8.30	6.06	---	3.35	0.67	1.08	4.36	0.00	8.80	0.18	0.00
		3	11.7	870	428	8.30	5.53	---	3.30	0.67	1.08	4.36	0.00	8.90	0.18	0.00
	29/ 7/66	0	19.2	746	629	8.80	5.43	0.0	3.33	0.50	0.38	5.00	2.01	6.20	0.14	0.09
		1	19.2	732	749	8.80	2.30	0.0	3.30	0.52	0.46	4.90	2.72	6.40	0.14	0.24
		2	16.7	729	576	8.80	0.45	0.1	3.31	0.51	0.48	4.90	2.16	6.90	0.07	0.46
		3	15.3	781	738	8.60	0.00	4.0	3.28	0.57	0.48	5.20	1.28	8.10	0.24	0.52
BOITANO NE	10/ 5/66	0	16.1	595	338	7.70	----	---	3.20	0.49	0.68	2.33	0.00	5.01	0.10	2.80
	26/ 7/66	0	17.8	712	427	9.05	----	0.0	3.80	0.57	0.86	3.31	1.76	5.84	0.00	0.28
LAKE JACKSON	14/ 5/66	0	11.1	564	404	8.60	4.15	---	1.85	0.60	0.93	3.81	0.48	5.90	0.15	0.00
		1	11.7	562	393	8.70	4.04	---	1.85	0.60	1.00	3.85	0.56	5.90	0.15	0.00
		2	11.9	564	411	8.60	3.94	---	1.85	0.60	1.08	3.80	0.64	5.80	0.15	0.00
		3	10.6	673	471	8.50	2.02	---	2.05	0.71	1.32	4.31	0.48	7.00	0.18	0.00
	28/ 7/66	0	20.3	625	502	8.80	5.71	0.0	2.06	0.64	0.38	5.10	0.00	5.90	0.32	0.16
		1	18.9	624	488	9.00	4.87	0.0	2.10	0.62	0.38	5.20	1.08	5.20	0.35	0.91
		2	17.6	615	627	9.00	3.53	0.0	2.00	0.63	0.32	5.20	1.02	5.30	0.37	0.45
		3	16.7	625	537	9.00	3.14	0.0	2.00	0.63	0.34	5.20	0.88	5.50	0.40	0.20
EAST L.	16/ 5/66	0	12.2	481	349	8.00	5.21	---	3.05	0.45	0.76	1.42	0.00	5.24	0.16	0.13
		1	11.9	481	338	8.00	5.00	---	3.10	0.53	0.76	1.41	0.00	5.24	0.46	0.00
		2	11.7	489	333	8.00	4.95	---	3.10	0.49	0.76	1.40	0.00	5.24	0.21	0.48
		3	11.7	472	298	8.00	4.95	---	3.15	0.49	0.76	1.41	0.00	5.24	0.20	1.63
		4	11.7	474	335	8.00	4.68	---	3.05	0.53	0.76	1.41	0.00	5.24	0.20	1.23
		5	11.4	519	317	8.00	4.57	---	3.10	0.45	0.80	1.37	0.00	5.18	0.05	1.03
		6	11.1	645	272	7.90	3.94	---	3.15	0.45	0.82	1.32	0.00	5.18	0.03	0.61
	29/ 7/66	0	18.6	495	435	8.60	5.40	0.0	3.10	0.41	0.30	1.90	0.88	4.80	0.14	0.43
		1	18.6	495	407	8.60	5.38	0.0	3.29	0.42	0.34	1.90	0.96	4.60	0.16	0.00
		2	17.8	495	406	8.80	2.80	0.0	3.26	0.40	0.36	1.90	1.07	4.40	0.16	0.06
		3	16.7	497	398	8.70	1.90	0.1	3.41	0.38	0.32	1.90	0.88	4.70	0.11	0.23
		4	15.9	505	415	8.50	0.50	0.5	3.26	0.38	0.40	1.90	0.64	4.90	0.21	0.07
		5	15.0	508	394	8.30	0.56	0.6	3.31	0.38	0.40	1.90	0.00	5.60	0.14	0.00
		6	14.4	510	665	8.00	0.00	2.0	3.29	0.38	0.40	1.90	0.00	5.70	0.06	0.23
SP 6	15/ 5/66	0	13.3	240	97	7.70	6.75	---	0.27	0.11	0.86	1.47	0.00	2.60	0.08	0.00
		1	12.8	270	114	7.95	5.42	---	0.27	0.11	0.92	1.42	0.00	2.90	0.11	0.00
	31/ 7/66	0	24.2	256	131	9.00	7.22	0.0	0.41	0.75	0.80	2.20	1.07	2.12	0.00	0.04
		1	20.0	257	73	8.70	5.71	0.1	0.41	0.78	0.74	2.10	0.80	2.40	0.02	0.06
BOX 27	17/ 5/66	0	13.3	37	31	6.40	6.39	---	0.15	0.11	0.16	0.00	0.00	0.40	0.06	0.13
		1	12.8	44	42	6.40	5.59	---	0.12	0.11	0.26	0.00	0.00	0.29	0.11	0.15
	30/ 7/66	0	19.4	.41	--	9.15	4.20	0.0	0.02	0.07	0.06	0.16	0.12	0.14	0.02	0.01
		1	17.2	33	6	6.20	4.20	0.0	0.02	0.07	0.10	0.12	0.00	0.39	0.10	0.17

* Low values owing to interference with hydrogen sulfide

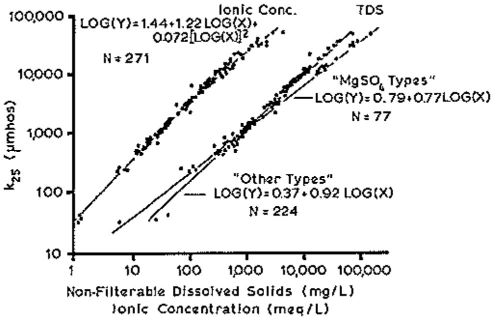


FIGURE 2. Relationships between conductivity, and total dissolved solids and total ionic content.

Significant differences in total ionic concentration were observed within lakes, as well as seasonally both within and between lakes. Chemical stratification was most conspicuous in those lakes which were deeper than 5 m (e.g., White L.) or with conductivities > 5 000 micromhos (e.g., Long L. and Barnes L.), but less pronounced in the relatively shallower and fresher lakes. Seasonal differences in vertical stratification, also more conspicuous in the deeper more concentrated lakes (e.g., Long L., Round-Up L., and Lake Lye), resulted from partial or complete mixing of higher conduc-

TABLE III

Percentage composition by weight of bottom muds from lakes in central British Columbia

Lake	Depth (m)	Particle Sizes (mm)					
		0.15	0.15–0.42	0.42–0.59	0.59–0.83	0.83–1.98	>1.98
LB 2	0	48.64	18.27	9.03	3.27	5.50	15.28
LB 1	0	82.04	12.49	2.93	0.52	0.51	1.48
Barnes L.	0	51.59	20.20	7.08	3.51	2.42	1.30
Bower's L.	0	73.56	21.39	6.51	1.39	0.54	0.50
Round-up L.	0	46.21	25.93	8.51	7.99	7.95	7.45
Lake Lye	0	40.86	15.15	6.07	5.89	8.41	23.62
LE 5	0	67.62	13.92	14.45	1.48	1.03	1.51
	1	74.72	21.19	3.10	0.60	0.12	0.28
Boitano L.	0	24.24	11.32	6.86	5.43	6.27	45.88
Rush	0	43.53	30.06	11.48	4.62	3.25	7.06
Barkley L.	0	81.98	9.29	2.16	2.31	2.34	1.89
	1	69.75	19.70	4.53	1.40	1.30	3.29
	2	72.22	12.53	3.99	4.05	0.89	0.29
LE 3	0	68.26	13.27	7.71	7.32	2.11	1.30
	1	61.46	11.15	6.17	8.38	11.46	1.35
LE 4	0	68.69	24.59	3.07	2.19	0.48	0.95
	1	64.57	16.65	5.38	12.56	0.65	0.16
Six Mile	0	43.18	14.51	5.57	5.06	4.04	27.65
Lake Greer	0	40.77	9.38	2.64	1.92	2.31	42.95
	1	45.49	19.60	8.29	5.95	7.35	13.29
	2	93.26	2.42	3.28	1.03	0.00	0.00
Rock L.	0	51.94	32.11	5.95	2.76	3.49	3.73
	1	72.86	9.80	5.02	4.64	3.48	4.17
GR 3	0	52.47	27.44	10.89	4.38	3.04	1.75
Nr. Phalarope	0	33.21	25.04	10.55	14.23	7.72	9.22
	1	62.22	6.35	2.81	3.05	10.63	14.91
Westwick L.							
South End	0	62.85	17.45	4.32	1.73	8.45	5.21
Sta. 'A'	0	59.31	17.99	3.87	1.59	2.12	11.34
Sta. 'B'	0	51.43	29.65	7.79	5.02	4.88	1.23
Sta. 'C'	0	64.11	20.45	2.93	1.35	10.59	0.57
Sta. 'D'	0	65.09	29.13	4.07	0.96	0.46	0.30
Sta. 'E'	0	38.52	30.85	8.05	3.26	4.16	15.16
Sta. 'F'	0	81.36	15.98	2.03	0.37	0.17	0.08
Sta. 'G'	0	84.36	7.59	3.51	1.69	1.07	1.78
Sta. 'H'	0	55.26	15.26	6.10	3.53	4.35	15.51
Lac du Bois	0	43.98	22.83	7.61	4.60	4.95	16.00
Nr. Op. Cr.	0	79.51	17.65	1.70	0.61	0.29	0.21
	1	86.31	7.79	1.85	2.76	0.76	0.50
	2	69.61	17.94	5.26	1.97	2.08	3.10
	3	88.67	8.97	0.88	0.81	0.20	0.43
Box 17	0	91.44	6.44	0.64	0.44	0.22	0.65
	1	83.32	7.32	1.80	1.29	1.38	4.79
	2	49.12	27.29	6.81	4.86	4.84	7.04
Lake Jackson	0	53.29	20.33	10.00	4.76	4.43	7.17
	1	69.14	16.41	4.58	3.28	3.48	3.08
	2	56.67	28.25	5.50	1.99	5.67	1.88
East L.	0	68.88	16.37	5.01	4.37	3.71	1.66
	1	66.76	14.87	6.34	4.12	4.27	3.61
	2	60.25	17.08	11.10	5.55	4.01	1.98
	3	82.20	13.23	2.07	1.25	0.67	0.56
	4	55.52	19.65	4.19	11.10	7.30	2.21
	5	94.47	3.96	0.76	0.26	0.29	0.23
Sp 6	0	79.37	10.73	3.15	2.04	1.29	3.42
Box 27	0	87.15	8.65	1.77	1.19	0.79	0.45

TABLE IV

Percentage of organic carbon content in bottom muds from lakes in central British Columbia

	Depth (m)					
Lake	0	1	2	3	4	5
Clinton						
Goodenough L.						
LB 2	15.68					
LB 1	1.47					
Long L.						
Barnes L.	2.47					
Bower's L.	6.97					
LE 1						
LE 2						
Round-Up L.	4.90					
Lake Lye	7.22					
White L.						
LE 5	5.20	9.18				
Boitano L.	6.52					
Rush	8.20					
Barkley L.	5.24	6.95	6.46			
LE 3	6.83	7.31				
LE 4	9.10	11.18				
Six Mile	8.09					
Lake Greer	1.92	1.70	5.03			
Rock L.	1.46	7.72	7.94			
GR 3	14.44					
Nr. Phalarope	4.20	10.61				
Westwick L.						
South end	12.25					
Sta. 'A'	8.51					
Sta. 'B'	11.27					
Sta. 'C'	6.48					
Sta. 'D'	3.07					
Sta. 'E'	5.41					
Sta. 'F'	6.32					
Sta. 'G'	15.45					
Sta. 'H'	8.74					
Sorenson L.						
Lac du Bois	7.14					
Nr. Op. Cres.	9.83	7.33	8.78	11.05		
Box 17	4.27	13.17	8.39			
Boitano NE						
Lake Jackson	5.43	7.42	9.95			
East L.	4.92	6.80	11.52	8.74	6.31	11.12
Sp 6	7.22					
Box 27	4.36					

tivity bottom waters with lower conductivity surface waters which would form in early spring owing to ice melt and snow run-off. Seasonal differences in chemical concentration between the lakes were most conspicuous in the relatively shallower, more concentrated lakes (e.g., Goodenough L. and Bowers L.) in which seasonal differences appeared primarily because of concentration by evaporation and dilution by run-off. Of course, alternate seasonal cycles of evaporation and dilution also may have been present in the deeper, higher conductivity lakes.

Mixing was almost certainly incomplete in LB 1, Long L., and White L. and quite likely incomplete in Barnes L., Round-Up L., and Lake Lye. Thus three to six of the lakes were meromictic. The permanent chemical stratification of White L. has been described by Northcote and Halsey (1969).

TDS is significantly correlated with conductivity (r-0.919) and similar patterns of seasonal and vertical variation were observed between and within the lakes.

Temperature

Significant differences were observed in the vertical distribution of temperature in different lakes, as well as seasonally within and between the lakes.

In general, the lakes were homeothermal in their upper 2 m and lakes shallower than 3–4 m or with conductivities $<$ 5 000 micromhos were essentially isothermal throughout, suggesting polymixis. The deeper lakes or lakes with higher conductivities were usually thermally stratified below two metres. Seasonal differences within the lakes ranged from inverse stratification during winter in Long L. and Westwick L. to homeothermal conditions in the shallower lakes and thermal stratification in the deeper or higher conductivity lakes. Seasonal differences within the lakes were greatest in lakes located in the southeastern portion of the study area and least in the northwestern portion. Scudder (1969*a*) has shown that the surface waters of the lakes throughout the region undergo wide daily fluctuations. During this study, a maximum surface temperature of 27.6 C was measured on 8 August in LB 1.

Lakes with depths greater than 3–4 m or with conductivities $>$ 5 000 micromhos were either second-class, dimictic lakes or meromictic lakes. LB 1, a meromictic lake, was inversely stratified during spring with a temperature of 14.7 C at the surface and 18.6 C at 4 m, and appeared to have a temperature minimum at 3 m during August. Clearly, depth and completeness of mixing, in addition to other factors such as exposure to wind and elevation, affected temperatures both between and within the lakes.

pH

The lakes differed significantly in pH both with regard to season and depth ($P<0.05$). However, significant differences in the seasonal pattern of vertical distribution of pH were not detected. In general, pH's were higher during late July and August, although the seasonal changes were relatively greater in the less well-buffered, lower conductivity lakes. Differences in the vertical distribution between the lakes appeared to be related to circulation within the lake.

Highest pH's were measured in Goodenough L. (10.2) and the lowest in Box 27 (6.20). In general, higher pH ($>$9.0) was measured in sodium carbonate-bicarbonate and sodium sulphate-type lakes, while lower pH ($<$9.0) was measured in magnesium sulphate and sodium types of lower conductivity.

Dissolved Oxygen

Significant differences in seasonal vertical distribution of oxygen was detected both between and within lakes. The trend for decreasing oxygen concentration with increasing depth was characteristic of the series of lakes, even though oxygen concentration was relatively uniform with depth in lakes shallower than 3–4 m. Seasonal differences in the vertical distribution of oxygen in different lakes was primarily attributable to the occurrence of different mixing patterns in the lakes. Those lakes, which appeared to lack thermal stratification and had relatively uniform oxygen concentrations with depth, are probably polymictic. Pronounced oxygen depletion was observed during late summer in those lakes which were seasonally stratified thermally or chemically and anærobic conditions were observed during spring and late summer in the bottom waters of those lakes which were presumably meromictic (e.g., Lake

Lye and White L.). Winter oxygen depletion was observed in all but the largest of the lakes.

In general, lower oxygen concentrations were measured in those lakes with higher TDS concentrations resulting from decreasing solubility of oxygen with increasing salinity and higher oxygen concentrations made possible by lower water temperatures during spring in all the lakes. However, supersaturation was apparent in the surface waters of some lakes during late summer (e.g., White L., LE 3, LE 4, Barkley L., and SP 6).

Hydrogen sulphide

Hydrogen sulphide was measured semiquantitatively during July and August and was inversely related to dissolved oxygen concentration. However, both were detected at the same depth on various occasions, suggesting that hydrogen sulphide was diffusing into those areas from its site of generation. Maximum concentrations of 5 ppm were estimated.

Major ionic constituents

The major ions by concentrations were sodium, potassium, calcium, magnesium, bicarbonate, carbonate, chloride, and sulphate. The relative composition and concentrations of these cations and anions differed considerably between the lakes, both seasonally and with respect to depth. Fifty-six of the 64 potential combinations of these eight ions were significantly correlated; however, high correlations (r-0.9) were found only between sodium and carbonate, sodium and chloride, magnesium and sulphate, and carbonate and chloride. Coefficients of variation (r^2) were 0.9 only for sodium and chloride, magnesium and sulphate, and carbonate and chloride, suggesting the primary associations between the ions were as the compounds magnesium sulphate, sodium carbonate, and sodium chloride.

In general, the ratios of K/Na, Ca/Mg, and divalent/monovalent ions are all substantially lower than reported for African lakes (Talling and Talling, 1965).

Anions. The major anions were carbonate-bicarbonate, sulphate, chloride in the ratio of 3.8:2:1. In general, the anions formed three discrete groups (Fig. 3). Fresher lakes were principally carbonate-bicarbonate types with a tendency toward increasing chloride concentration and increasing total ion content in the Gang Ranch and Riske Creek areas. Sulphate lakes were all of higher solute content and were located in the Clinton and Kamloops areas. The third group consisted of lakes with mixtures of carbonate-bicarbonate-sulphate. These lakes were not restricted to any particular geographic area.

The vertical distribution of each of the ions differed significantly between the lakes, the concentrations of carbonate and chloride differed significantly seasonally between the lakes and the vertical distribution of bicarbonate within lakes differed significantly seasonally. Less pronounced differences ($0.05>P>0.01$) in the seasonal concentration of bicarbonate between lakes and the seasonal concentration of chloride within lakes also were measured. Sulphate concentration increased with depth in lakes with higher conductivities (e.g., LB 2, LB 1, and Long L.) and substantial seasonal difference was apparent in the concentration of sulphate in LB 2; however, these trends were not characteristic of the entire series of lakes. The significant differences in the vertical distribution of each of the ions between the lakes was principally a result of the different mixing patterns represented by the series (i.e., meromixis, dimixis, and polymixis). Seasonal variation within and between the lakes in the more conservative chloride ion is more likely owing to mixing within the lakes with vertical redistribution of the ion, whereas seasonal variation in carbonate is likely because of a seasonal change in absolute content.

Cations. Relative concentrations of major cations are shown in Figure 4. The average proportions of the cations were sodium, magnesium, potassium, calcium in the ratio of 57.1:26.1:2.6:1. Calcium and potassium were grouped together in Figure 4, because of their relatively low concentrations.

In general, the cations formed a continuous series with magnesium and sodium predominant, although calcium and potassium were relatively more common in lakes with low solute concentrations. There is a tendency for

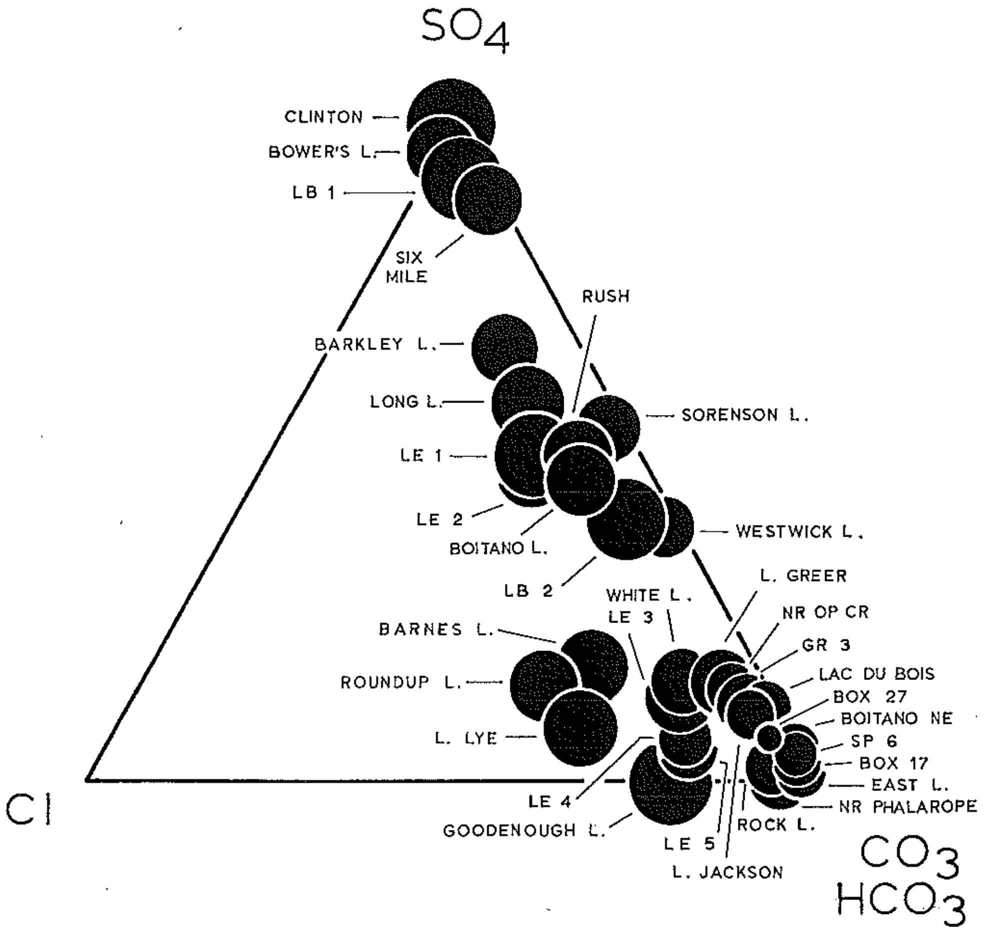


FIGURE 3. Triangular co-ordinate plot of relative anion concentration in relation to total solute concentration. Diameters of the circles representing the lakes are proportional to the solute concentrations of the lakes.

sodium to replace magnesium as the major cation with increasing solute concentrations; however, this trend is masked by Clinton L., Six Mile L., and LB 1 in which magnesium is the predominant cation (in the Kamloops and Clinton areas).

The lakes differed significantly with regard to their vertical concentrations of sodium, potassium, calcium, and magnesium and with regard to their seasonal concentrations of sodium, potassium, and calcium. The vertical differences between the lakes resulted primarily from their difference in patterns and completeness of circulation, while their seasonal differences are primarily because of evaporation and concentration in shallower more concentrated lakes and partial or complete mixing during spring in stratified lakes.

Sodium was always present at concentrations higher than potassium and the relative concentration of sodium to potassium increased as a function of conductivity (Fig. 5). The loga-

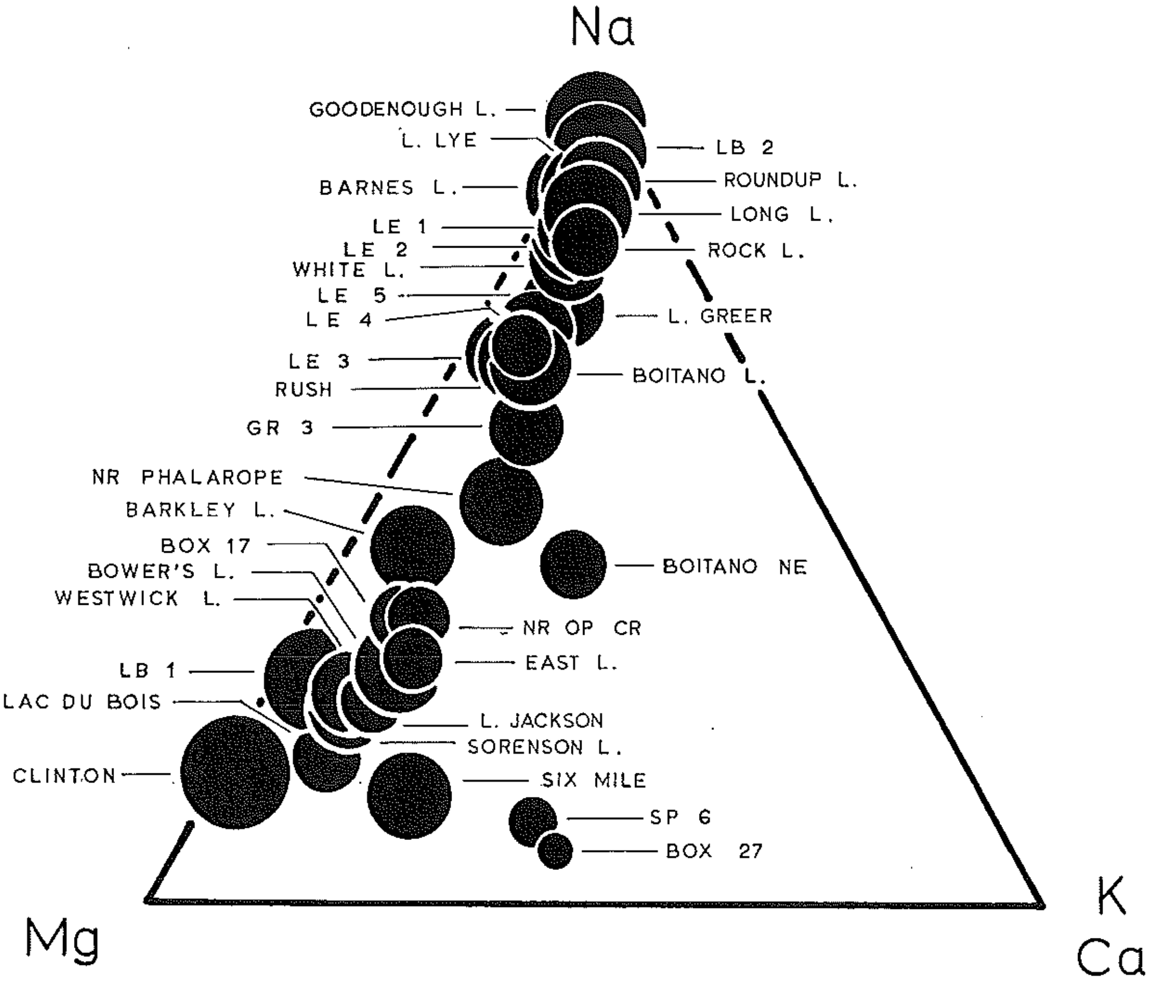


FIGURE. 4 Triangular co-ordinate plot of relative cation concentration in relation to total solute concentration. Diameters of the circles representing the lakes are proportional to the solute concentrations of the lakes.

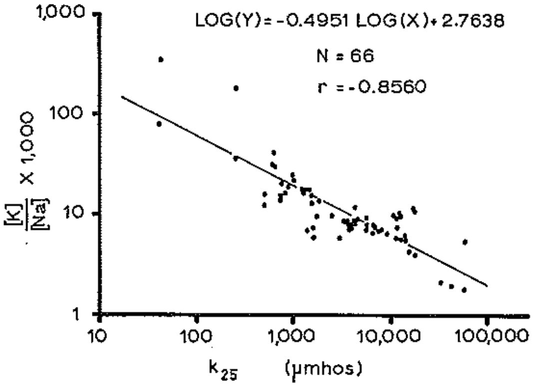


FIGURE 5. Relationship between the logarithm of the ratios between the concentrations of calcium and sodium x 1 000 and the logarithm of conductivity.

rithm of K/Na is significantly correlated with the logarithm of conductivity.

Calcium was relatively low in all lakes except Bower's L., Six Mile L., and Clinton L. In these lakes, pH was relatively low and sulphate was the major anion and magnesium the major cation. The logarithm of Ca/Mg was negatively correlated with the logarithm of conductivity (Fig. 6).

The ratio of divalent to monovalent cations indicates the monovalent ions predominate (Fig. 7). The logarithm of their ratio was negatively correlated with the logarithm of conductivity.

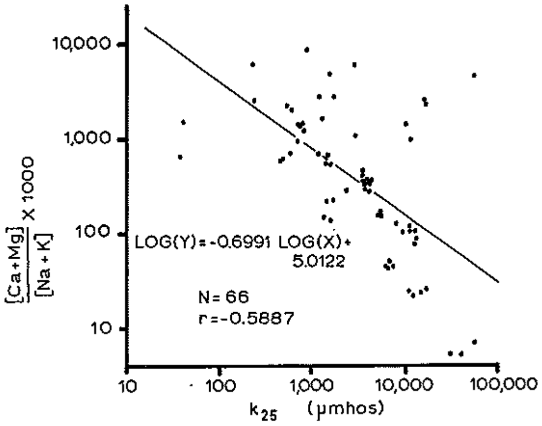


FIGURE 6. Relationship between the logarithm of the ratios between the concentrations of calcium and magnesium x 1 000 and the logarithm of conductivity.

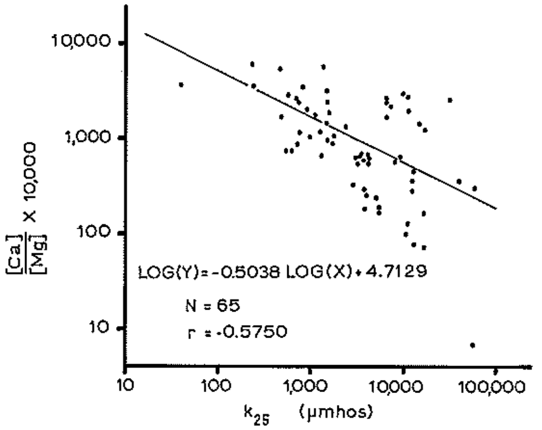


FIGURE 7. Relationship between the logarithm of the ratios of concentrations of divalent and monovalent cations x 1 000 and the logarithm of conductivity.

Characteristics of the substratum

Samples of bottom mud were collected with an Ekman dredge from metre intervals in water depth in most of the lakes, but only at the margins of the remaining lakes. In general, silt and very fine sand comprised greater than 50 per cent of the substratum of all the samples (Table III). No superficial pattern other than increase in percentage of silt and very fine sand and decrease in granules with increased depth was apparent.

Substratum samples also were analysed for percentage of organic carbon (Table IV). No pattern was apparent in organic carbon present in substratum at the margins of the different lakes. Organic carbon present in the muds did increase with depth of water. Because the mud samples were collected only once, the data permit no conclusion about the relative productivity of the lakes.

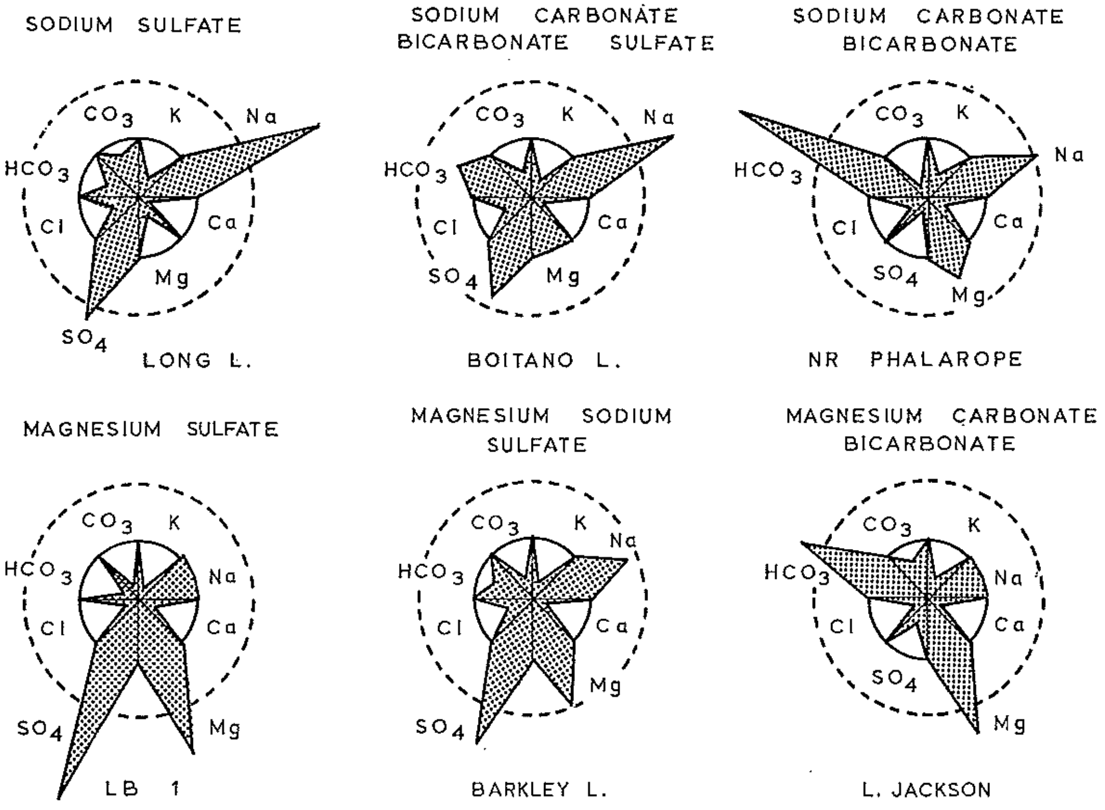
Discussion

Arid conditions sufficient to result in closed lakes are widespread in Saskatchewan, Alberta, central Washington, and the Interior plateau regions of British Columbia, and elsewhere. Saline lakes from both Saskatchewan and Washington are well known (Anderson, 1958*a*, *b*; Castenholz, 1960; Edmondson, 1963; Hammer *et al.*, 1975; Rawson and Moore, 1944). In general, magnesium and sulphate are the predominant ions in Saskatchewan lakes of higher ionic concentrations, while sodium and bicarbonate-carbonate are the predominant ions in higher concentration Washington lakes. However, in central British Columbia, the lakes differ considerably in their ionic concentrations and relative ionic composition: the most striking feature is their considerable chemical heterogeneity. In general, magnesium and sulphate predominate at higher ionic concentrations, whereas sodium bicarbonate-carbonate and complex mixtures of magnesium, sodium, sulphate, bicarbonate, and carbonate predominate at lower ionic concentrations. Goodenough L. is unusual in that sodium and carbonate are the predominant ions. Chloride, though sometimes present at higher concentrations than sulphate, occurred at relatively lower concentrations than reported for lakes of comparable solute concentration in Washington and Saskatchewan.

Cummings (1940) reported sodium carbonate-bicarbonate waters to be characteristic of relatively arid regions of British Columbia underlain by Tertiary basaltic lava flows, magnesium sulphate waters of areas underlain by argillite, quartzite, and limestone, and sodium sulphate waters of areas underlain by greenstone and diorite. However, the general complexity of the geology in the central parts of British Columbia and the lack of quality in the geological data from the study areas precludes this type of interpretation of the chemical diversity between the lakes.

Chemical differences between lakes have been explained in terms of the chemical weathering of crystalline rocks and subsequent geochemical evolution by evaporative concentration and equilibrium with the atmosphere (Hecky and Kilham 1973), but the absence of precise geological data, together with the complete absence of hydrologic data, preclude this type of analysis now. Nevertheless, the lake types observed (Fig. 8) are consistent with the types generated by Hardie and Eugster (1970) in their theoretical computer study of evolution of closed basin brines. Kilham (1971) has argued that calcium concentration is the factor decisive to the ultimate lake type derived by evaporative concentration.

However, the primary goal of this study, in addition to describing the chemical differences between the lakes and seasonal patterns of variation within the lakes, was to develop some rationale for ranking or categorizing the lakes according to their physicochemical properties, to facilitate interpretation of the differential faunal distributions and relationships already described (Cannings, 1973; Scudder, 1969*a*, *b*; Scudder and Mann, 1968; Topping, 1971 and 1975; Topping and Acton, 1976), and to direct appropriate experimental analyses of the situations. The high ionic concentrations present suggest that dissolved solids may be responsible for many of the faunal relationships, but the concentrations of individual ions, the concentrations of ions which may act synergistically, or total ionic concentration (of osmotic significance) may each be the limiting


SODIUM SULFATE

SODIUM CARBONATE BICARBONATE SULFATE

SODIUM CARBONATE BICARBONATE

LONG L.

BOITANO L.

NR PHALAROPE

MAGNESIUM SULFATE

MAGNESIUM SODIUM SULFATE

MAGNESIUM CARBONATE BICARBONATE

LB 1

BARKLEY L.

L. JACKSON

FIGURE 8. Ionic diagrams showing six basic 'chemical types' of lakes present.

factor in particular circumstances. Hence, some means of considering the physicochemical properties of the lakes is required which does not neglect any particular aspect.

Numerous attempts have been made to rank or categorize lakes according to their environmental and biotic similarities and differences; however, most of these schemes have dealt either with a restricted segment of the biota of a lake (e.g., Brundin, 1958; Macan, 1955; Rawson, 1956; Seddon, 1972; Thienemann, 1918) or with the influence of one or more morphometric properties on the relative productivity of lakes (*see* Brylinsky and Mann, 1973; Schindler, 1971). Because lake water chemistry is one of the most pronounced environmental variables of closed lakes and because organisms adapt to their abiotic environment rather than vice versa, classification of the lakes on the basis of their physicochemical properties is particularly important.

A chemical approach frequently used to categorize lakes is identification of their predominant cations and anions (Blinn, 1971; Cole, 1968; Hansen, 1969; Hutchinson, 1957; Northcote and Halsey, 1969; Rawson and Moore, 1944; Scudder, 1969*a, b*; Scudder and Mann, 1968; Talling and Talling, 1965; Williams, 1967). When the lakes are classified in this manner, six principal lake types are obtained (Fig. 8). This approach has utility; however, identification of the predominant ions is not always easy. Relative anionic concentrations (Fig. 3) indicate that three distinct categories of lakes are present, but the nearly continuous series of relative cationic concentrations (Fig. 4) clearly precludes use of combinations of cations and anions to identify categories (i.e., unless one wishes to obtain as many categories as lakes, thereby suggesting each lake is unique). Larkin and Northcote (1958) have come to a similar conclusion. An obvious alternative is to classify lakes according to their ionic concentrations (e.g., Talling and Talling, 1965). However, this approach does not emphasize the importance of ionic composition. Of course, both approaches may be combined, but the end result is not very precise and though differences may be distinguished, similarities are difficult to quantify. As well, no evaluation of the importance of the interactions of the ions can be made. Hence, some method giving equal weight to composition, concentration, and the interactions of these conditions is required.

Methods of cluster analysis developed for numerical taxonomy (Sokal and Sneath, 1963) provide one approach which satisfies the criteria of ranking according to similarity, giving equal weight to diverse characters and allowing for the importance of the interaction of those characters. Though the methods of numerical taxonomy are not universally accepted or appreciated, their value is clear in geology (*see* Bonham-Carter, 1967). Moreover, Shannon and Brezonik (1972) and Sheldon (1973) have used cluster analysis to classify lakes. The approach has the clear advantage of reproducibility and predictability.

In the present attempt to classify the British Columbia lakes, characters used were temperature; pH; conductivity; and concentrations of sodium, potassium, calcium, magnesium, carbonate, bicarbonate, chloride, and sulphate. Remaining chemical and physical data were not used because they were either too qualitative (e.g., hydrogen sulphide concentration) or because the data were incomplete (e.g., organic content and substratum composition). The standardized character states of these physicochemical properties were calculated and correlations between the lakes computed using the standardized properties. Pair-wise clusters of similar lakes were formed using the unweighted pair-group method of analysis described by Sokal and Sneath (1963) and the resulting clusters were then plotted against their correlation coefficients (Fig. 9). Thus, the lakes were classified using all the available, complete physicochemical data and the crucial issue of deciding whether chemical composition or concentration is more important was avoided by considering both simultaneously and equally.

In general, the numerical classification of the lakes indicates one major dichotomy of types with the two branches ultimately yielding 13 groups of lakes, each with a similarity of $r \sim 0.9$. In general, the groups correspond to differences in total ionic content, although the inclusion of Clinton Lake and LB 1 with the more fresh lakes is a clear and outstanding exception. None of the resulting associations are sur-

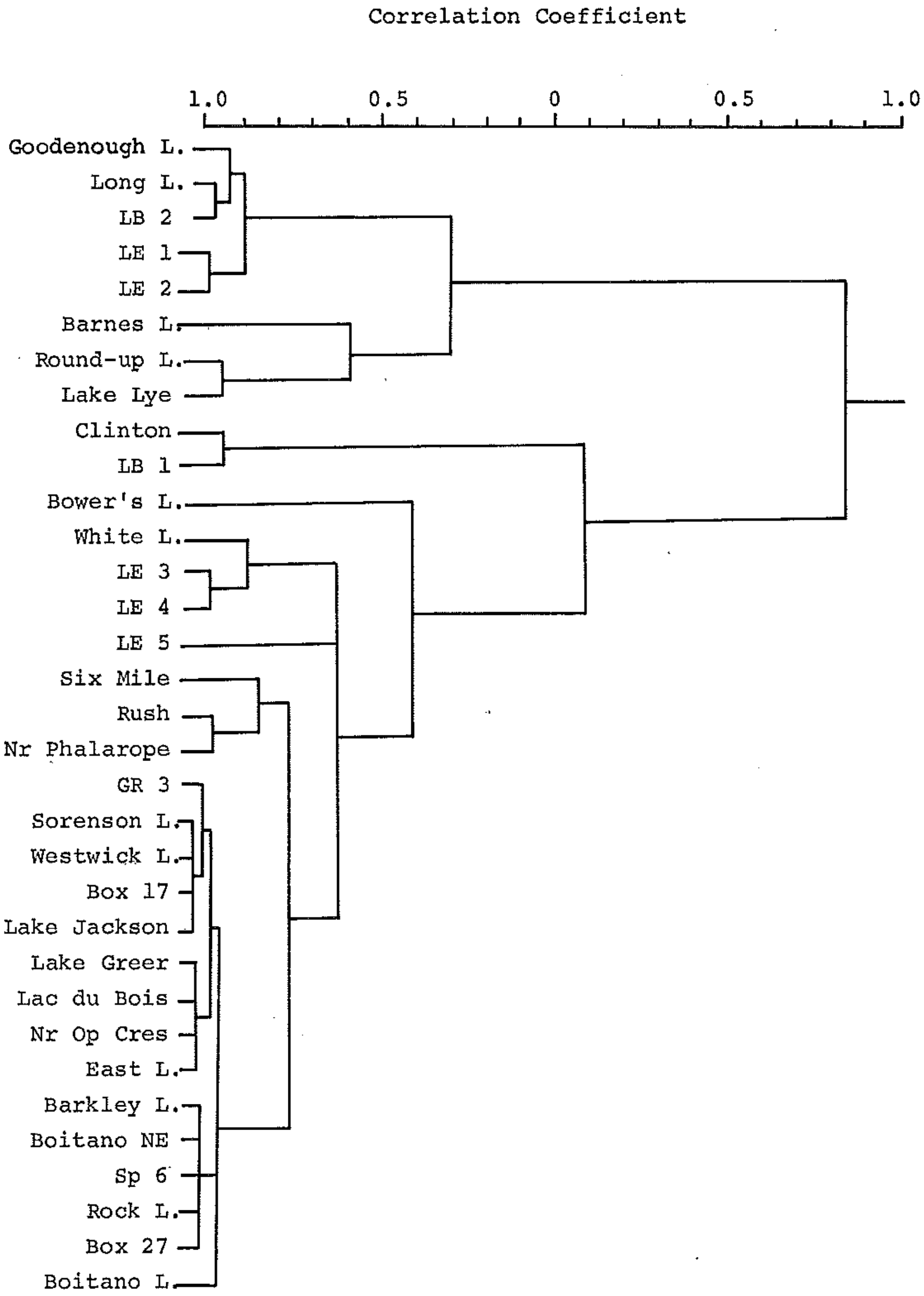


FIGURE 9. Cluster analysis of the 33 lakes using 13 physicochemical properties.

prising, because no *a priori* assumptions about ranking could be developed from the individual data. The implications of the ranking are interesting in that lakes located at the extremities of the study area are most similar in some cases (e.g., Long L. and LB 2 are similar, while Lac du Bois is most similar to Near Opposite Crescent, East L., and L. Greer). Presumably, these lakes are most similar with regard to their total properties and, providing the organisms have had the opportunity, should be inhabited by the same species.

As Schindler (1971) has pointed out, most attempts to rank or categorize lakes are based on one or a few components of the lake ecosystem and this approach is no exception. However, morphometric characteristics, as well as any other type of character, could be incorporated into the classification and the result should be better resolution and a more stable classification. As well, the analysis could be performed on localities within, as well as between lakes, to determine if different horizontal or vertical locations differed significantly. Finally, different techniques of numerical taxonomy could produce different dendrograms (Moss, 1968; Sokal and Michener, 1967; Minkoff, 1965).

This analysis provides a basis for further study in that it provides a scheme against which a similar numerical analysis of floras and faunas of the lakes can be compared. Concordance and discordance can then readily be assessed. One would expect the faunas and floras to bear some relationship to the degree of difference between the lakes. Finally, this analysis provides a basis for further experimental studies (e.g., simple transplant experiments among the more similar lakes) to determine if the physicochemical properties of the lakes used in this analysis are indeed limiting.

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