Hydrobiologia 162: 275–286 (1988)

Physico-chemical limnology of eleven, mostly saline permanent lakes in western Victoria, Australia

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Received 3 February 1987; in revised form 26 June 1987; accepted 21 July 1987.

Abstract

Major physico-chemical features of eleven, mostly saline permanent lakes situated on volcanic terrain in western Victoria, Australia, are described. All are large (1.1 to 251 km^2 in area), and most are shallow ($\bar{z}$ = <6 m). Mean salinities were 0.3 to 56.6 g l^{-1}, and seasonal differences were slight. Major ion dominances were Na > Mg > Ca ≷ K : Cl > HCO_3 + CO_3 > SO_4. Generally, pH was 8.0 to 9.0. Nitrogen not phosphorus appeared to be a limiting plant nutrient. The shallow lakes were often highly turbid and had low secchi disc transparencies (sometimes <5 cm).

Introduction

There are numerous saline and a few freshwater lakes in western Victoria, Australia. Williams (1981a) has reviewed pre-1979 studies of them. Mostly, these studies concern either small, highly saline, shallow and ephemeral lakes, or large, deep, permanent maar lakes. Surprizingly few concern the large, shallow, permanent and only moderately saline (salinity <60 g l^{-1}) lakes which dominate the landscape in this region. Such lakes include some of the largest permanent lakes on mainland Australia, Lake Corangamite being the largest. Increasing attention is now being accorded them (e.g. Williams, 1981b; De Deckker, 1982; Timms, 1983), since they are unlike most Australian salt lakes; the latter are *not* permanent and have salinities seasonally well above 60 g l^{-1}.

Eleven of these large, permanent lakes, most of them shallow, and all with salinities less than 60 g l^{-1}, were studied in 1979–1980. The major physico-chemical results of our studies form the basis of the present paper. Detailed results are given as technical appendices in an addendum to a document issued by the Environmental Protection Authority of Victoria and prepared by Gutteridge, Haskins and Davey Pty Ltd (1980).

Study lakes

The position of the study lakes is indicated in Fig. 1. Table 1 gives morphometric data on them, and shows that all are large (1.1 to 251 km^2 in area), and all but three (Bullen Merri, Gnotuk and Purrumbete) are shallow (mean depth <6 m). Values for shoreline development are low (1.1 to 2.8), with Lake Gnotuk, an almost circular maar lake, having a value of 1.1. Values for volume development are high (~1.5 to ~2.6), viz. the lakes are generally shallow with flat bottoms. All lakes lie on a volcanic terrain in an area generally referred to as the 'western district' of Victoria.

Seasonal fluctuations in lake water levels were not recorded, but from March 1979 to May 1980 no significant changes in water levels were noticed in any

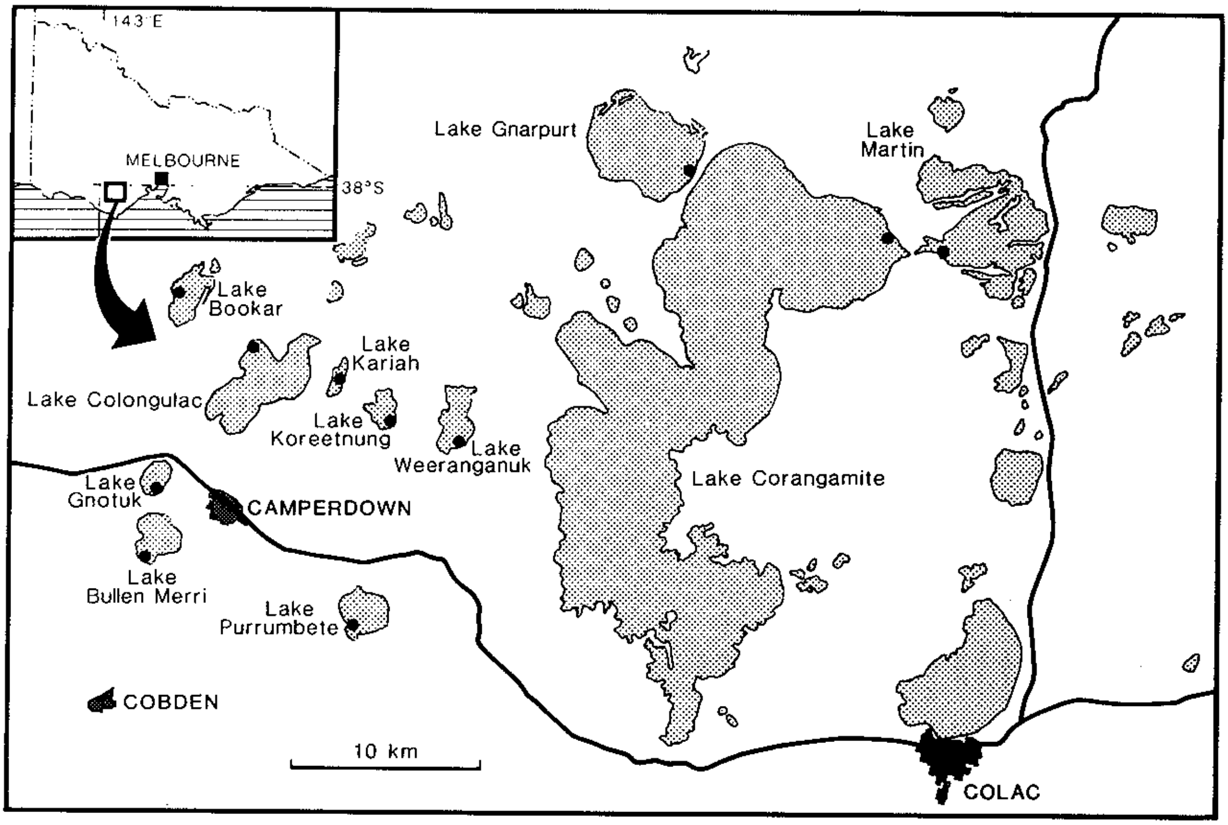

Fig. 1. Location of study lakes. Solid circles within individual lakes indicate sampling position.

Table 1. Morphometry of study lakes.

Lake	Surface area (ha)	Volume ($m^3 \times 10^6$)	Maximum depth (m)	Mean depth (m)	Volume development	Shoreline length (km)	Shoreline development	Maximum length (km)	Maximum breadth (km)	Major source of data[1]
Purrumbete	552	157	45	28.5	1.9	10.3	1.2	3.21	2.89	B
Martin	4020	79	<3[2]	2.0	~2.0[3]	34.0	1.5[3]	8[4]	6[4]	A
Bullen Merri	488	192	66	39.3	1.7	8.78	1.1	2.62	2.56	B
Kariah	110	0.6	0.8[5]	0.55	2.1[3]	5.1	1.4[3]	2[4]	0.7[4]	A
Colongulac	1460	32	3.9[5]	2.2	1.7	23.0	1.7[3]	7[4]	3.5[4]	A
Gnarpurt	2732	70.3	<3[2]	2.57	~2.6[3]	25.0	1.3[3]	7.0[4]	5.5[4]	A
Koreetnung	228	1.4	1.0[5]	0.61	1.8[3]	7.2	1.3[3]	2[4]	1.7[4]	A
Weeranganuk	440	3.0	<1[2]	0.68	~2.0[3]	11.6	1.6[3]	3.5[4]	1.5[4]	A
Bookar	485	2.4	2.0[5]	0.49	0.7	13.7	1.7[3]	3.5[4]	1.5[4]	A
Corangamite	25160	1509	~6.0[2]	6.0	1.8[3]	159	2.8[3]	32.5[4]	12.5[4]	A
Gnotuk	208	32	18.5	15.3	2.5	5.71	1.1	1.96	1.37	B

[1] A, Gutteridge *et al.* (1980) [to end 1979]; B. Timms (1976).
[2] Estimated.
[3] Calculated from given data.
[4] Derived from topographic maps.
[5] Timms (1983).

lake. However, longer-term, secular, variations in lake levels are known, and several of the study lakes are known to have been dry during the past century. The periodicity and overall trend of this secular variation is indicated by simulations of past levels in Lakes Bullen Merri and Colongulac from 1898 to 1979 (Figs. 2 and 3). The simulations were based upon rainfall recorded at Camperdown from 1898, and water levels recorded by the State Rivers and Water Supply Commission from 1969 to 1979 at Lakes Bullen Merri, Gnotuk, Colongulac and Purrumbete (see Gutteridge *et al.*, 1980, for details). As can be seen, the level of Bullen Merri has been dropping continuously since 1898 (some 14 m; for more details see Currey, 1970); in Lake Colongulac, on the other hand, the pattern has been more variable. Independent historical records confirm the essential validity of the simulations. Simulations for Lake Gnotuk are like those for Bullen Merri, though the rate of fall in the level has been less. Given that Lake Colongulac morphometry is similar to that of the other study lakes except for Gnotuk, Bullen Merri and Purrumbete, the pattern of secular variation in water level shown by Lake Colongulac has probably

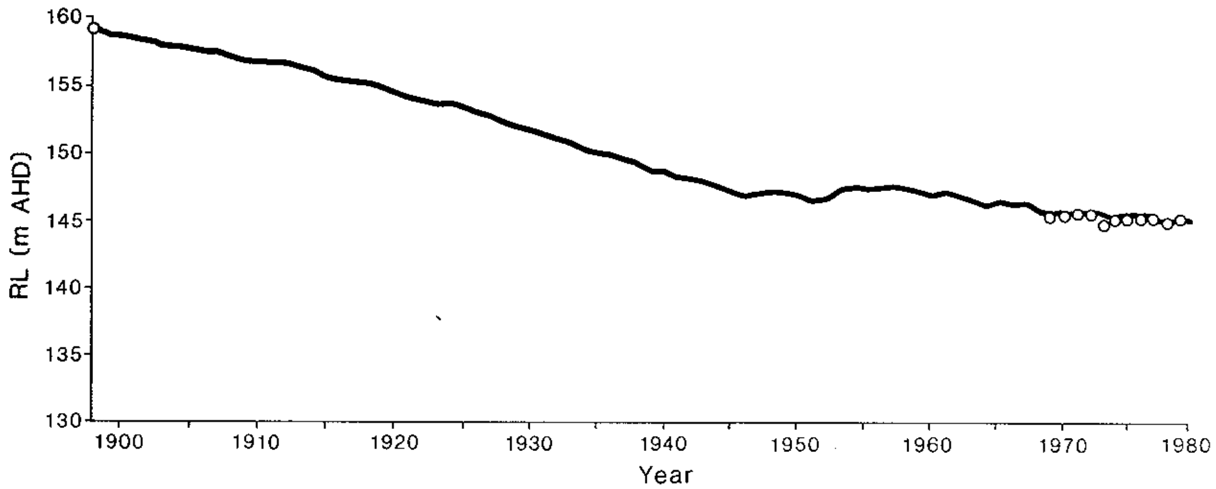

Fig. 2. Lake Bullen Merri water level simulation. Open circles indicate observed summer water levels. RL (m AHD), water level in metres above Australia Height Datum [sea-level]. After Gutteridge *et al.* (1980).

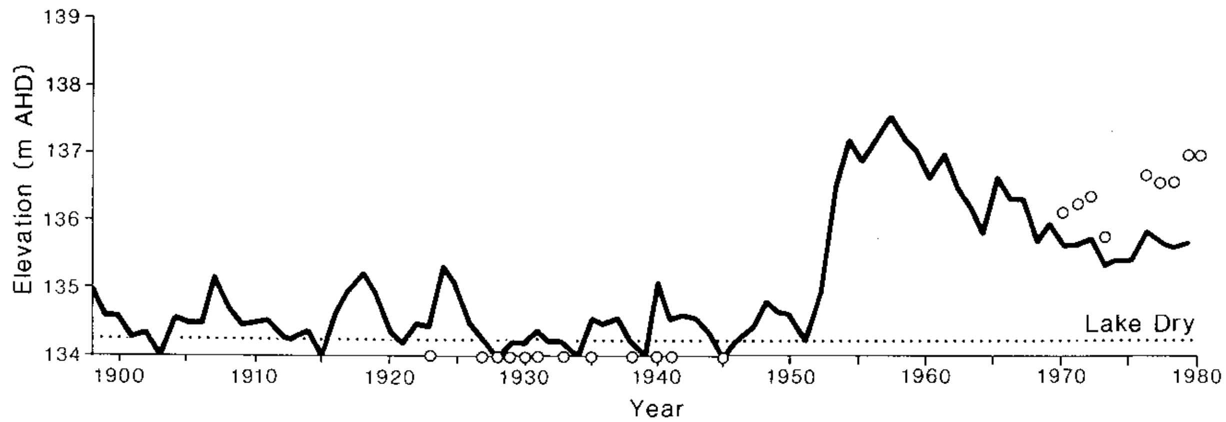

Fig. 3. Lake Colongulac water level simulation (1898–1978). The levels shown assume no waste inflow. Open circles indicate observed summer water levels (with waste inflow). Elevation (m AHD), water level above Australian Height Datum [sea-level]. After Gutteridge *et al.* (1980).

been similar to that of the other shallow study lakes. Thus, most of these, too, will often have been dry during the past century. The only exception appears to be provided by Lake Corangamite (Alexander, Sutcliffe and Knight, 1956). There is evidence that Lake Corangamite was at some stage much more extensive (see Currey, 1964).

The climate of the region is moist and temperate. Average annual rainfall varies from 50 cm (north) to 70 cm (south). Average maximum air temperature is about 27 °C in summer, and about 10 °C in winter. Average annual evaporation is near 150 cm. The large evaporation and the topography (which produces a system of inland drainage) account for the elevated salinities of most lakes in the region. Records of rainfall at Camperdown from 1898 reflect the extent of climatic fluctuation from year to year (Fig. 4).

Methods

The lakes were visited either monthly or bi-monthly from March 1979 to May 1980.

Water samples were collected in black polyethylene bottles from just beneath the surface at one point on the margin of a lake. Samples for nitrogen and phosphorus analyses were immediately stored on ice for transit to the laboratory. All major ion and nutrient analyses used methods given in APHA (1975). Field pH was determined with a Metrohm meter. Conductivity was derived in the laboratory using a Radiometer instrument, turbidity with a Hach turbidometer. Water temperatures were measured just below the lake surface with a mercury-in-glass thermometer.

Results and discussion

Salinity

Salinities over the period of investigation are detailed in Table 2. The data are derived from conductivity measurements using the formula of Williams (1986a). Although the tabulated data are from samples at a single point in a lake, they seem likely to have been representative of salinities throughout the lake. Samples taken from two widely separate points at three of the study lakes on two occasions (Bullen Merri, Corangamite, Gnotuk: 25.4.1979 and 19.6.1979) indicated negligible surface differences between sampling points (see also Bayly and Williams, 1966; Williams, 1981a). Individual samples were also probably representative of salinities throughout the water column for all the study lakes are exposed to the strong winds characteristic of the region; even in the deepest lakes (Bullen Merri, Gnotuk, Purrumbete) vertical salinity differences were never recorded by Timms (1976).

Only weak seasonal fluctuations in salinity occurred. Salinities were generally highest in March

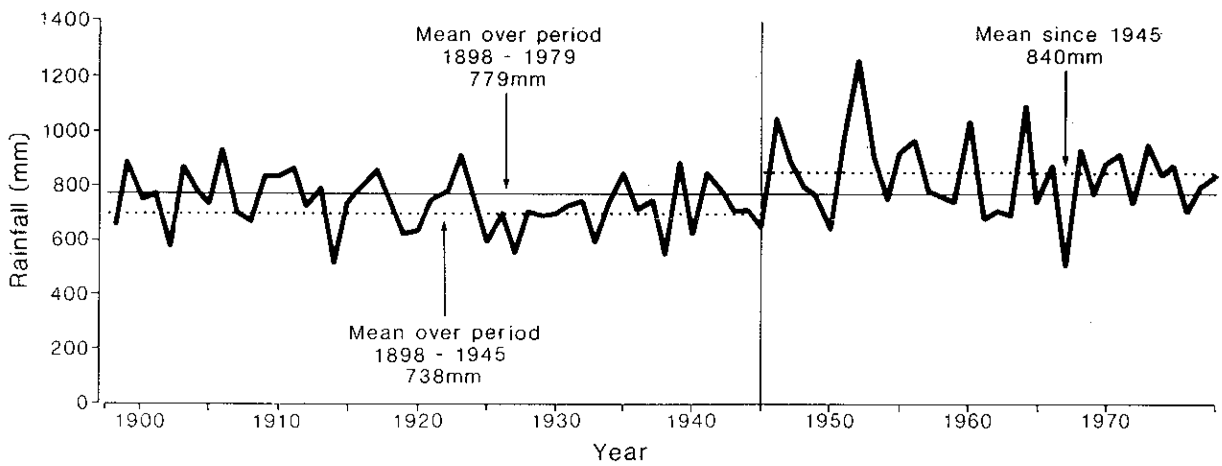

Fig. 4. Mean annual rainfall at Camperdown, 1989–1974. From Gutteridge *et al.* (1980).

Table 2. Salinity data (values as g l^{-1}).

Lake	15.3.79	25.4.79	23/24.5.79	19/20.6.79	29/31.7.79	29/30.8.79	23/24.9.79	25.10.79	30.11.79	14/15.1.80	27.2.80	11.3.80	26.5.80
Purrumbete	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.4	0.4	-
Martin	2.9	3.2	3.3	3.3	3.6	3.5	3.6	3.3	4.2	4.8	8.1	8.1	8.4
Bullen Merri	8.1	8.1	8.0	7.7	8.7	8.2	7.9	5.0	8.7	8.1	8.3	8.8	9.1
Kariah	9.7	10.7	10.7	10.2	9.3	7.8	6.1	4.4	6.0	7.7	13.1	15.6	11.7
Colongulac	10.8	11.0	10.8	10.7	11.2	10.1	9.3	8.3	10.2	9.9	11.3	12.1	11.7
Gnarpurt	10.0	9.7	9.7	9.6	10.5	9.9	9.8	7.2	11.0	11.3	12.7	13.5	13.7
Koreetnung	12.5	13.3	13.1	13.3	12.3	11.0	9.2	5.6	9.6	10.4	-	15.1	14.5
Weeranganuk	14.8	16.2	15.9	15.5	16.5	12.7	11.1	9.1	11.5	13.4	-	21.0	19.4
Bookar	15.4	15.5	15.3	15.1	15.3	14.5	13.1	11.3	13.3	14.5	14.3	18.0	17.4
Corangamite	32.9	31.7	31.2	31.3	32.5	27.1	29.6	26.8	30.8	30.1	36.3	34.9	33.2
Gnotuk	56.5	54.0	53.0	56.5	54.4	54.8	51.8	51.9	57.9	53.3	57.1	58.0	58.2

Table 3. Extent of variation in salinity over period March 1979 to May 1980.

Lake	Mean salinity ($g\ l^{-1}$)	Salinity range ($g\ l^{-1}$)	Max.-min. salinity ($g\ l^{-1}$)	Max.-min. salinity / mean salinity × 100 (percent)
Purrumbete	0.3	0.3 – 0.4	0.1	33
Martin	4.6	2.9 – 8.4	5.5	119
Bullen Merri	8.0	5.0 – 9.1	4.1	51
Kariah	9.5	4.4 – 15.6	11.2	118
Colongulac	10.6	8.3 – 12.1	3.8	36
Gnarpurt	10.7	7.2 – 13.7	6.5	61
Koreetnung	11.7	5.6 – 15.1	9.5	81
Weeranganuk	14.8	9.1 – 21.0	11.9	80
Bookar	14.9	11.3 – 17.4	6.1	41
Corangamite	31.4	26.8 – 36.3	9.5	30
Gnotuk	55.2	51.8 – 58.0	6.2	11

1980 (late summer/early autumn) and lowest in October 1979 (spring). There was no correlation between the extent of salinity fluctuation in absolute values and mean salinity (Table 3), nor any obvious correlation with mean depth (Table 1). This pattern of seasonal fluctuation contrasts strongly with that of temporary and highly saline lakes in this region. In these, salinities often fluctuate annually from $<50\ g\ l^{-1}$ to $>350\ g\ l^{-1}$ and show a well-defined seasonal pattern (cf. Williams and Buckney, 1976).

Despite the absence of marked seasonal fluctuations, all study lakes have probably exhibited considerable secular fluctuations in salinity. Thus, the salinity of Lake Corangamite (data are most abundant for this lake) appears to have varied from $>100\ g\ l^{-1}$ to $\sim 12.5\ g\ l^{-1}$ between 1866 and 1980 (Fig. 5). Adding our data to earlier data on Bullen Merri and Gnotuk (Timms, 1973) indicates that in these lakes, too, secular trends in salinity superimposed upon weak seasonal fluctuations have occurred. In Lake Gnotuk, for example, salinity appears to have risen gradually from about 47 $g\ l^{-1}$ in 1965 to a mean of about 56 $g\ l^{-1}$ in 1979. Secular salinity variations undoubtedly relate to long-term climatic change (cf. Fig. 4), but the impact of farming in the past century, notably by clearing native vegetation, irrigation and pumping from bores, must also have had some effect.

To indicate the extent to which the salinity of the study lakes is typical of other saline lakes in the area, a large number (64) of salt lakes in the western district was sampled in January 1980. Thirteen of these (20 percent) had salinities between 3 and 10 $g\ l^{-1}$, 26 (41) had salinities between 10 and 60 $g\ l^{-1}$, and 25 (39) had salinities higher than 60 $g\ l^{-1}$. Clearly, all but one of the study lakes (Purrumbete) fall within the second category (10–60 $g\ l^{-1}$) with respect to mean salinity. This range of salinity is that characterized by the occurence of halophiles (*sensu* Williams, 1981a; Timms, 1983).

Major ion composition

Numerous major ion analyses of western district salt

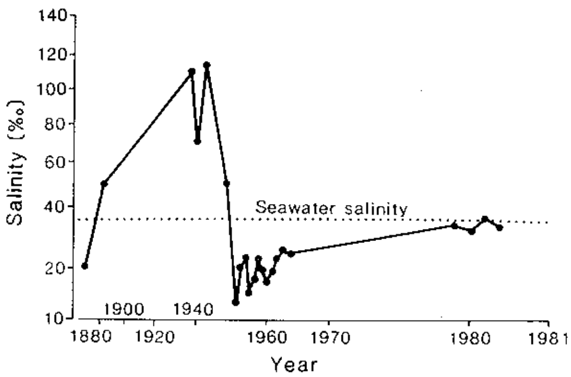

Fig. 5. Secular fluctuations in salinity at Lake Corangamite, 1866–1980. Recent data have been added to the historical data recorded in Bayly and Williams (1966).

lakes have been published (beginning with those for Lake Corangamite by Johnson [in Wilson, 1879] and Craig and Wilsmore (1892)). Williams (1981a) reviewed them. The analyses demonstrate the remarkable ionic homogeneity of the lakes, with Na and Cl always dominant. The only variation involves the relative importance of K and Ca, and of HCO_3 + CO_3 and SO_4. For that reason, major ions were determined on only two occasions (March and August, 1979). The results are given in Table 4, and confirm predictions. Thus, ionic dominances were: Na > Mg > Ca > K : 7 lakes (mean salinities, 0.3–14.8 g l^{-1}); Na > Mg > Ca = K : 1 lake (14.9 g l^{-1}); Na > Mg > K > Ca : 3 lakes (8.0–55.2 g l^{-1}); Cl > HCO_3 + CO_3 > SO_4 : all lakes (0.3–55.2 g l^{-1}). The only feature contrary to previous observations is that in both Corangamite and Gnotuk, the two most saline lakes, HCO_3 + CO_3 was more abundant than SO_4. This is not surprising since the lakes occur in a volcanic terrain which, through rock weathering, characteristically causes lakes to remain highly alkaline.

pH

Table 5 summarises the detailed monthly data on pH. No seasonal trends nor correlations with salinity could be discerned. Indeed, the data are remarkably constant; in most of the saline lakes, pH varied little more than 1 unit over the period of observation, indicating the well-buffered nature of the lake water. All the lakes generally had a pH value >8, as do most lakes in this region (Williams, 1981a).

Table 4. Major ion composition.

Lake	Date	Salinity (g l^{-1})	Ca	Mg	Na	K	Σ Cations (m. equiv.)	HCO_3 + CO_3	Cl	SO_4	Σ Anions (m. equiv.)
			(mg l^{-1})					(mg l^{-1})			
Purrumbete	15.3.79	0.43	17	31	86	4.7	7.3	150	121	17	6.6
	29/30.8.79	0.44	20	31	87	3.2	7.4	156	128	20	6.7
Martin	15.3.79	2.91	32	100	892	15	49	250	1570	52	50
	29/30.8.79	3.58	42	106	1107	17	59	292	1950	60	62
Bullen Merri	15.3.79	8.12	16	248	2615	88	137	650	4500	<1	141
	29/30.8.79	8.68	17	250	3110	93	159	640	4570	<1	142
Kariah	15.3.79	9.79	18.5	197	3200	19.5	157	1160	4870	330	168.5
	29/30.8.79	8.75	17	167	3280	35	158	880	4110	260	139
Colongulac	15.3.79	10.58	55.5	305	3385	104	175	1020	5600	112	183
	29/30.8.79	10.50	45	194	3690	100	181	760	5600	108	176
Gnarpurt	15.3.79	9.50	65	378	2955	37	164	450	5320	295	167
	29/30.8.79	10.47	74	407	3600	47	195	488	5530	328	172
Koreetnung	15.3.79	12.22	23	260	4245	15	208	780	6735	160	210
	29/30.8.79	11.78	24	236	4340	26	210	740	6275	142	195
Weeranganuk	15.3.79	14.91	44	381	4985	16	251	720	8225	410	255
	29/30.8.79	13.26	38	322	4840	30	240	635	7055	340	219
Bookar	15.3.79	14.82	25	413	4925	48.5	251	970	8370	66	257
	29/30.8.79	14.95	24	394	5410	55	270	820	8190	61	250
Corangamite	15.3.79	32.52	55	968	11075	141	569	850	18790	645	562
	29/30.8.79	27.46	44	790	9260	120	473	765	15950	530	477
Gnotuk	15.3.79	57.21	137	2475	18460	608	1029	730	34740	64	996
	29/30.8.79	53.66	124	2210	15740	400	883	740	34390	59	988

Table 5. Summary of monthly pH determinations (March 1979-March 1980).

Lake	Mean salinity (g l^{-1})	Range pH	Max.-min. pH
Purrumbete	0.3	6.8 – 9.1	2.3
Martin	4.6	7.0 – 8.75	1.75
Bullen Merri	8.0	8.4 – 9.3	0.9
Kariah	9.5	8.6 – 9.4	0.8
Colongulac	10.6	8.2 – 9.25	1.05
Gnarpurt	10.7	7.1 – 8.85	1.75
Koreetnung	11.7	8.5 – 9.2	0.7
Weeranganuk	14.8	8.0 – 9.15	1.15
Bookar	14.9	8.3 – 9.3	1.0
Corangamite	31.4	7.9 – 9.05	1.15
Gnotuk	55.2	7.9 – 8.7	0.8
Total		6.8 – 9.4	2.6

Phosphorus and Nitrogen

The concentration of phosphorus and nitrogen in western district lakes has not been well-investigated thus far, except for Lake Werowrap (Walker, 1973). Moreover, most previous analyses are of doubtful validity. In the present study, all lakes were sampled on four occasions and concentrations of orthophosphate-phosphorus, total phosphorus, nitrate-nitrogen and Kjeldahl nitrogen determined. Ammonia-nitrogen concentrations were determined on two occasions. Tables 6 and 7 give results.

It is clear that considerable fluctuations in both phosphorus and nitrogen concentrations occurred, and, although patterns appeared which may be of a seasonal nature within individual lakes, no consistent overall pattern of fluctuation was discernible.

Table 6. Orthophosphate-phosphorus and total phosphorus concentrations. Data as $\mu g\ l^{-1}$.

Lake	Phosphorus species[1]	25.4.79	19.6.79	30.8.79	Oct. 79
Purrumbete	A	31	110	59	79
	B	42	130	77	110
Martin	A	5	26	17	23
	B	130	140	97	170
Bullen Merri	A	2	5 – 33	11	5
	b	32	27 – 57	33	29
Kariah	A	220	260	210	170
	B	390	410	420	310
Colongulac	A	5000	4400	4300	4100
	B	5200	5400	4500	4500
Gnarpurt	A	31	28	65	38
	B	190	170	220	170
Koreetnung	A	130	33	56	59
	B	350	39	230	390
Weeranganuk	A	170	160	90	95
	B	320	310	210	330
Bookar	A	150	130	130	160
	B	350	290	220	390
Corangamite	A	9	12	37	15
	B	140	110	130	150
Gnotuk	A	210	210	240	230
	B	470	330	390	430

[1] A, orthophosphate-phosphorus; B, total phosphorus.

Table 7. Concentrations of nitrogen species. Data as $\mu g\ l^{-1}$.

Lake	Nitrogen species[1]	25.4.79	19.6.79	30.8.79	Oct. 79
Purrumbete	A	70	190	190	60
	B	5	ND[2]	ND	<40
	C	120	350	500	290
	D	195	540	690	390
Martin	A	<30	90	<10	<20
	B	5	ND	ND	50
	C	300	1900	1300	1000
	D	335	1990	1310	1070
Bullen Merri	A	<30	70 – 120	<10	<20
	B	8	ND	ND	<30
	C	190	470 – 660	1100	310
	D	228	540 – 780	1110	360
Kariah	A	90	80	<10	<20
	B	14	ND	ND	<40
	C	360	3500	2500	1000
	D	464	3580	2510	1060
Colongulac	A	260	310	<10	60
	B	18	40	60	130
	C	340	3400	2200	1800
	D	618	3750	2270	1990
Gnarpurt	A	100	130	<10	60
	B	53	ND	ND	50
	C	400	3500	2400	810
	D	553	3630	2410	920
Koreetnung	A	<30	80	<10	<20
	B	24	ND	ND	200
	C	410	4800	1900	2000
	D	464	4880	1910	2220
Weeranganuk	A	<30	80	30	<20
	B	25	ND	ND	50
	C	360	2400	2300	1200
	D	415	2480	2330	1270
Bookar	A	170	100	20	<20
	B	11	ND	ND	510
	C	400	6500	4000	2100
	D	581	6600	4020	2620
Corangamite	A	280	150	250	30
	B	30	ND	ND	<70
	C	710	7200	6000	2100
	D	1020	7350	6250	2200
Gnotuk	A	120	90	90	90
	B	22	ND	ND	<70
	C	920	520	5600	1200
	D	1062	610	5690	1360

[1] A, nitrate-nitrogen: B, ammonia-nitrogen; C, Kjeldahl nitrogen; D, total nitrogen (approx.).
[2] Not determined.

Leaving aside concentrations in Lakes Colongulac, the concentrations of ortho- and total phosphorus were considerably higher than are usually encountered in most standing bodies of fresh water. Lake Colongulac had extremely high concentrations of phosphorus which undoubtedly reflected the discharge of sewage effluent from a water treatment plant on its southern shore. In all lakes, concentrations of nitrogen fell well within the lower range of concentrations found in most fresh waters.

It is interesting to consider these particular points in a more general way bearing in mind lacustrine trophic categories of oligotrophy, mesotrophy and eutrophy. Such trophic categories are widely applied to freshwater lakes but have been applied with difficulty to saline lakes. On the basis of nitrate-nitrogen concentrations, the study lakes would be considered generally to be oligotrophic, whereas on the basis of total phosphorus concentrations all would be considered generally as eutrophic. The frequently high concentrations of phosphorus in many Australian salt lakes was alluded to by Williams and Wan (1972) who, at the same time, pointed to the apparent absence of high amounts of associated biomass commonly found with such high concentrations. Our data suggest a possible explanation for this apparent anomaly, at least so far as the study lakes are concerned. It is that nitrogen not phosphorus is the limiting plant nutrient. Thus, when total nitrogen:phosphorus and inorganic nitrogen:phosphorus ratios are considered (Table 8), it is seen that – in so far as these ratios do indicate nutrient limitation – most of the lakes appear to be limited by nitrogen, a few by nitrogen and/or phosphorus, and only one (Lake Corangamite) by phosphorus.

Apart from Lake Colongulac, the basis of this limitation remains unexplained. For Lake Colongulac, excess concentrations of phosphorus clearly come from the input of treated sewage. This pattern of nitrogen:phosphorus ratio, it may be added, is the converse of that recently found to be the case in a series of highly saline lakes on the Yorke Peninsula of South Australia (Tominaga, Tominaga and Williams, 1987). In these lakes, phosphorus appears to be the limiting nutrient in lakes of comparable salinity to the study lakes; it is only at very high salinities (>140 g l^{-1}) that nitrogen appears to become limiting.

Surface water temperatures

Single temperature readings at monthly intervals are

Table 8. Nitrogen:phosphorus ratios.

Lake	Range Total N/P	Mean Total N/P	Range Inorganic N/P	Mean Inorganic N/P	Limiting element
Purrumbete	3.6 – 9.1	5.3	1.3 – 3.2	2.1	N[1,2]
Martin	2.3 – 14.3	9.0	0.6 – 7.0	3.5	N[1,2]
Bullen Merri	6.2 – 33	16.8	0.9 – 19	9.5	N and/or P[1,2]
Kariah	1.3 – 8.8	4.9	0.1 – 0.5	0.3	N[1,2]
Colongulac	0.1 – 0.7	0.4	<0.1 – 0.6	<0.1	N[1,2]
Gnarpurt	3.2 – 21	10.1	0.2 – 4.9	3.2	N and/or P[1], N[2]
Koreetnung	1.4 – 126	35.3	0.2 – 3.7	1.7	P[1], N[2]
Weeranganuk	1.9 – 10.9	6.1	0.3 – 0.7	0.4	N and/or P[1], N[2]
Bookar	1.7 – 23	12.5	0.2 – 3.3	1.4	N and/or P[1], N[2]
Corangamite	7.1 – 66	34	6.7 – 34	15.1	P[1,2]
Gnotuk	1.8 – 14.6	5.5	0.4 – 0.7	0.5	N[1,2]

[1] On the basis of total N/P, where (by weight) < 10 indicates N limitation, 10 – 17 P and/or N limitation, and > 17 P limitation (Forsberg *et al.*, 1978).

[2] On the basis of inorganic N/P, where (by weight) < 5 indicates N limitation, 5 – 12 N and/or P limitation, and > 12 P limitation (Forsberg *et al.*, 1978).

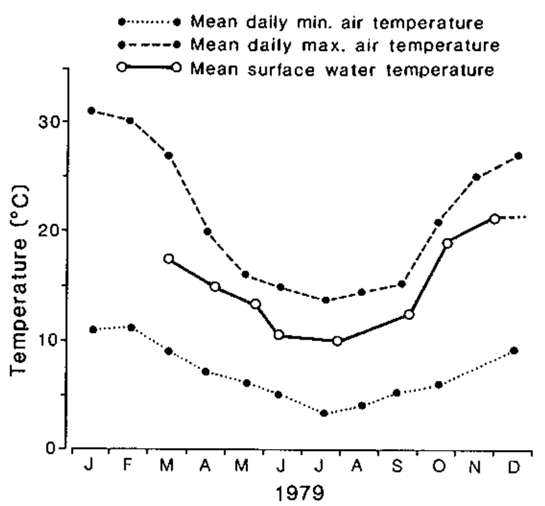

Fig. 6. Seasonal pattern of surface water temperature, 1979. Values derived by averaging data from all study lakes. Air temperature data from township of Alvie.

not likely to provide more than the broad pattern of seasonal fluctuation and for this reason detailed data are not documented. Instead, Fig. 6 shows the broad pattern of seasonal change as indicated by averaging all results for the lakes each month. The figure shows how the surface water temperatures closely reflect air temperature (data on air temperatures recorded at Alvie, a small township near Colac). In the shallow lakes, mixing of the water column no doubt results in uniform vertical temperature profiles, but in the deeper lakes a seasonal thermal stratification is known to develop (Timms, 1973).

Table 9. Secchi disc transparency and turbidity.

Lake	Secchi depth range (m)	Turbidity (NTU)
Purrumbete	0.5 – >1.0	1 – 38
Martin	0.03 – 0.25	3 – 260
Bullen Marri	0.18 – >1.0	1 – 36
Kariah	0.03 – 0.19	28 – 310
Colongulac	0.17 – 0.56	7 – 93
Gnarpurt	0.18 – 0.33	18 – 104
Koreetnung	0.01 – 0.34	27 – 215
Weeranganuk	0.01 – 0.16	25 – 295
Bookar	0.07 – 1.0	9 – 115
Corangamite	0.41 – >1.0	4 – 67
Gnotuk	>1.0	1 – 6

Secchi disc transparency and turbidity

Values for secchi disc transparency were often low and variable in the shallow lakes, and higher and more stable in the deeper lakes. Often in the shallow lakes, values were remarkably low, <5 cm (Table 9). No marked seasonal variation occurred. Turbidity values (Table 9) were also highly variable, with again no marked seasonal differences.

Conclusions

In so far as salt lakes have attracted the attention of limnologists (which, as pointed out recently by Williams (1986b), is not to any significant extent, given their great abundance, wide distribution and high scientific interest), most attention has been accorded highly saline localities that are either shallow and ephemeral or deep and permanent. Permanent, shallow, and only moderately saline lakes have attracted less attention. Perhaps this is because their physico-chemical conditions are perceived as having less dramatic biological effects. Whatever the case, there are many features of such lakes which merit attention, not least their occupancy by halophiles (rather than halobionts) and salt tolerant freshwater species.

The main purpose of the present paper is to document some of the major physico-chemical parameters of a series of large, permanent, mostly shallow, and fresh to only moderately saline lakes in western Victoria. Despite the large number of lakes of this sort in western Victoria, rather little basic information is available on them, as indicated previously. Noteworthy physico-chemical features of the lakes are: (1) the remarkable similarity of major ion dominances in all the saline lakes, (2) dampened salinity fluctuations and lack of marked seasonal salinity change, (3) little pH variation (thus well-buffered waters), (4) indications that nitrogen appears often to be limiting as a plant nutrient, and (5) frequently high (but always variable) turbidity values in the shallow lakes.

Acknowledgements

The work reported here was undertaken by us for Gutteridge, Haskins and Davey, consulting engineers, Melbourne. A report of it was submitted to the Environmental Protection Agency of Victoria as part of a policy review of environmental protection of lakes in the western district of Victoria. We thank both Gutteridge, Haskins and Davey Pty Ltd and the Environment Protection Authority of Victoria for permission to publish those data of scientific interest. Particular thanks go to Mr. Alan Strom of Gutteridge, Haskins and Davey Pty Ltd, for his support and enthusiasm. Most chemical analyses were undertaken by East Melbourne Laboratories, and we acknowledge this with thanks.

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