The Ionic Composition of Some Lowland Lake Waters from Cheshire, England

EVILLE GORHAM

Freshwater Biological Association, Ambleside, England

ABSTRACT

Analyses are presented for the major dissolved constituents in waters from nine Cheshire meres. Calcium and bicarbonate ions predominate, but there are also large proportions of magnesium, sodium, sulphate, and chloride in these rather concentrated waters. The two lakes lacking inflow and outflow streams are chemically aberrant, and it appears that their ionic composition is greatly influenced by that of rain. The chemistry of the normal mere waters reflects the arid conditions in which the underlying Keuper marls were deposited.

INTRODUCTION

In studies of British fresh waters there has been a marked tendency to concentrate upon the predominantly upland areas of older and harder rocks, and in particular a good deal is known of both the physical background and the biology of waters in the English Lake District (Macan and Worthington 1951). In contrast, the lowland lakes have received rather little attention, apart from scattered floristic and faunistic investigations. However, some of the Cheshire meres have recently been examined by Lind (1944, 1951; Lind and Galliford 1952), chiefly with a view to ascertaining the composition of the phytoplankton and the factors influencing it; and it seemed worthwhile to inquire into the chemistry of these waters in some detail, not only in the hope that it would lead to some further understanding of such lowland waters, but also to provide some comparison with the relatively well-known waters of the Lake District (Mackereth 1957).

My thanks are due to Dr. H. B. N. Hynes for collecting several of the samples, and providing notes on the sites; and to Mr. P. Hamer for the other samples. Mr. J. Heron kindly made the analyses for nitrate, phosphate, and silica.

SITES INVESTIGATED

The samples analyzed came from nine bodies of water near Northwich: a small lake near Sandiway, Oak Mere, Whitegate New Pool, Hatch Mere, Budworth Pool, Rostherne Mere, Tatton Mere, Pick Mere, and Budworth Mere. They range in size from 1–2 acres (Sandiway) to 100 acres (Rostherne), and in altitude from about 240 feet (Sandiway, Oak, and Hatch Meres) to 60 feet (Budworth Mere). All lie on Triassic substrata (Keuper marl and Rhaetic beds), but the drift shown on the 1″ Geological Survey maps ranges from glacial sands and gravels (e.g. Sandiway, Oak, and Hatch Meres) to boulder clay and alluvium (e.g. Pick and Budworth Meres). Oak Mere and the lake at Sandiway differ from the others in being without either inflow or outflow streams. Budworth Pool has a strongly polluted inflow.

The phytoplankton of Oak, Hatch, Rostherne, and Budworth Meres has been studied by Lind (1944) and others. It is, with the exception of Oak Mere, characterized in general by large numbers, but relatively few species, of blue-green algae, and diatoms; while desmids (more characteristic of oligotrophic waters) are scarce in both species and numbers. Oak Mere is peculiar in being almost wholly dominated by the green alga *Botryococcus braunii*. A similar contrast is observed in the case of zooplankton, which at Oak Mere is abundant but very restricted in species (Lind and Galliford 1952, Galliford 1954). The principal species, *Bosmina obtusirostris*, is a northern form typical of oligotrophic lakes, and has not been recorded from any other mere in

TABLE 1. *Ionic composition of some Cheshire meres, and of the average fresh water of the world*

	Total salts m.equiv/L	pH	Na	K	Ca	Mg	HCO_3	Cl	SO_4	NO_3-N	PO_4-P	SiO_2
			m.equiv/L							ppm		
Sandiway	0.55	3.9	0.23	0.03	0.09	0.07	nil	0.28	0.27	0.07	0.001	1.0
Oak Mere	1.05	4.7	0.39	0.06	0.38	0.21	nil	0.50	0.54	0.05	0.02	1.4
Whitegate New Pool	3.14	7.8	0.54	0.08	1.70	0.82	1.51	0.71	0.92	0.06		
Hatch Mere	3.22	8.6	0.48	0.10	1.67	0.97	1.65	0.62	0.94	0.17		3.2
Budworth Pool	3.61	7.3	0.53	0.10	1.94	1.04	1.59	0.68	1.20	2.45	0.04	8.2
Rostherne Mere	4.28		0.62	0.11	2.60	0.98	2.00	0.68	1.50	0.53	0.11	1.3
Tatton Mere	4.48	7.8	0.88	0.12	2.34	1.15	2.39	0.87	1.21	0.02	0.05	
Pick Mere	6.01		0.89	0.12	3.35	1.66	2.93	0.96	2.09	0.08	0.07	2.6
Budworth Mere	6.99		1.30	0.16	3.65	1.88	3.10	1.30	2.51	0.57	0.29	2.6
Average of last seven (C)	4.53		0.75	0.11	2.46	1.21	2.17	0.83	1.48			
World average fresh water (W)	2.35		0.36	0.08	1.49	0.42	1.71	0.23	0.37	0.30	0.11	17.1
Ratio: C/W	1.9		2.1	1.4	1.7	2.9	1.3	3.6	4.0			

Cheshire. The shore vegetation at Sandiway and Oak Mere also lacks the reedswamp of *Phragmites* commonly fringing these meres. Concerning shore fauna, Dr. H. B. N. Hynes (private communication) describes Budworth Pool, Hatch, Rostherne, Pick, and Budworth Meres as rich, with plentiful *Gammarus*, *Asellus*, and (except at Pick Mere) molluscs. The fauna of Oak Mere is on the other hand sparse, and *Gammarus*, *Asellus*, and molluscs were not observed during his brief visit. Finally, it is stated by Boyd (1951) that the number of ducks and waders on Oak Mere is far fewer than on the other Cheshire meres, though the Common Gull often visits it in abundance.

METHODS

Surface waters were collected from the various meres during August 1954 (Tatton), October 1954 (Oak, Hatch, Pick, Rostherne, and Budworth Meres, and Budworth Pool), January 1955 (Sandiway), and October 1955 (Oak and Hatch Meres, Whitegate New Pool, and Budworth Pool). The samples were filtered through Whatman 541 filter papers, the first portion being discarded. Methods of analysis were those used by Gorham (1955); silica was estimated in the 1955 samples by the ammonium molybdate procedure, after reduction of the resultant yellow color to molybdenum blue.

RESULTS

The chemical data are presented in Table 1, in order of increasing total salt concentrations. The major ions are given as milliequivalents per litre, except for hydrogen ions, measured as pH. Dissolved nitrate, phosphate, and silica are shown as parts per million (ppm) of N, P and SiO_2. Since the differences between 1954 and 1955 samples from three meres were not of great importance, the data have been averaged. The average fresh water of the world (Conway 1942) is also represented in Table 1, and for comparative purposes the ratio of the normal Cheshire mere (average of last seven samples) to the world average is given in the final row.

Total salt concentration varies considerably in these waters. The lake at Sandiway is most dilute, with 0.55 m.equiv./L, while Oak Mere is about twice as concentrated. The other meres are extremely rich in salts, ranging from 3 to 7 m.equiv./L. Pick Mere and Budworth Mere, in the valley of the River Weaver, yielded the most concentrated waters.

Among the cations calcium is clearly dominant, except in the first two waters. Magnesium is next in importance, followed by sodium, which however preponderates strongly in the most dilute water from Sandiway. Potassium is by far the least plentiful of the four metal cations, as in

TABLE 2. *Ionic proportions in some Cheshire meres and other waters*

	Total salts m. equiv. /L	H	Na	K	Ca	Mg	HCO_3	Cl	SO_4
		m. equiv. per cent of total cations or anions							
Lake District rain	0.17	26	52	3.1	9	10	nil	58	42
Moor House blanket bog	0.38	32	40	1.9	12	13	nil	37	63
Sandiway	0.55	24	42	5.5	16	13	nil	51	49
Oak Mere	1.05	1	37	5.7	36	20	nil	48	51
7 Cheshire meres	4.53	nil	17	2.4	54	27	48	18	33
World average fresh water	2.35	nil	16	3.4	64	17	74	10	16
Sunbiggin Tarn, on limestone	2.73	nil	7	0.4	85	8	86	6	8

most fresh waters. Only the first two waters are acid, hydrogen ions being of considerable importance (0.13 m.equiv./L) in the Sandiway sample.

Of the major anions, bicarbonate is most abundant, except for Oak Mere and Sandiway where it is absent. In these waters sulphate and chloride are equally plentiful, while in the richer lakes sulphate is distinctly in excess of chloride.

The analyses for nitrate, phosphate, and silica were not made until some weeks after the samples had been collected and filtered, and so are not highly reliable. They show no relation to the concentrations of major ions, but this is not unusual. Nitrate and silica are highest in the heavily polluted Budworth Pool, the concentration of nitrate (2.5 ppm N) being especially remarkable. Nitrate is low (0.05 ppm N) in Oak Mere, where pollution is negligible; and also in Tatton Mere, the only water sampled in summer when nitrate is usually much reduced. Silica is lowest (1.0 ppm) in the Sandiway water. Dissolved phosphate is extremely high in Budworth Mere (0.29 ppm P), and in most samples this element is much more plentiful than in normal waters of the Lake District, an area of much harder rocks and less agricultural influence, where phosphate is usually very scarce (about 0.001–0.005 ppm P). Of the present series only Sandiway showed such a low phosphate concentration (0.001 ppm).

DISCUSSION

If the concentrations of major ions in Table 1 are recalculated to show their proportional contributions to total cations and anions, certain features of interest become apparent. It is evident that the last seven meres resemble one another closely in their ionic proportions, and differ strikingly from Oak Mere, and especially from the Sandiway water. These differences are illustrated in Table 2, where the seven similar meres are represented by an average figure and compared with the other two, and with other types of water.

The Sandiway sample, with its high acidity, resembles waters from blanket bog at Moor House (Gorham 1956), whose proportions are also given in Table 2. These surface bog waters are quite unaffected by chemical influences from the mineral soil beneath, and depend entirely upon atmospheric precipitation for their mineral supply. However, they differ from the Sandiway water in being strongly colored by peaty organic material, and also having a rather higher proportion of sulphuric acid. Nevertheless, the degree of similarity strongly suggests that the Sandiway lake, small and without inflow or outflow, may be merely a rather impermeable gathering ground for rain water. (According to Mr. P. Hamer, a layer of compacted sand, known locally as "Foxes' Bench", occurs beneath the surface soil, and may be responsible for holding up the water level.) This impression is strengthened by comparison with Lake District rain (Gorham 1955), whose proportions are likewise shown in Table 2. The rain water resembles Sandiway even more closely than does the bog water, although only one-third as concentrated. It has not, of course, been subject to evaporation.

Oak Mere is clearly intermediate in its ionic proportions between Sandiway and the normal Cheshire mere. Acidity is low, but while the proportion of calcium has risen considerably above that of Sandiway, it is by no means up to that of the other meres, and bicarbonate is still lacking. It seems likely that Oak Mere is also fed mainly by surface runoff, and not by springs or ground water in intimate contact with rich mineral subsoil. On this view its water represents rain, modified by contact with the surface soil over which it has flowed, but to a much lesser extent than in the other meres fed by ground water.

A point to be considered here is the fact that in 1951 the lake level (maximum depth 18 feet) was raised almost 2 feet by pumping from a nearby borehole. However, since the pH of the mere water is now just the same as before pumping took place (Lind and Galliford 1952—analyses of December 1948 and May 1951), marked residual effects would seem unlikely. The borehole water would almost certainly be rich in salts and therefore dense, and might be expected to sink to the bottom and seep away more rapidly than the incoming runoff.

The increased proportions of calcium and magnesium in Oak Mere as compared with Sandiway are presumably due to exchange of rain hydrogen ions (derived from atmospheric pollution by sulphuric acid, cf. Gorham 1955) for the divalent metal cations adsorbed in large amounts on soil colloids, though it is possible that some carbonates remain to be attacked in the horizons percolated by the runoff feeding the lake.

The assumption that Oak Mere is largely rain-fed is also strongly supported by what is known of its physiography and past history (see Lind 1952). It, like Sandiway, is a lake without inflow or outflow streams, lying on relatively high ground. It is however much larger (area 52 acres, maximum depth 18 feet), and so might be expected to receive water which has had longer and more intimate contact with mineral soil. Another feature of Oak Mere is the presence of a large peat deposit at one end, which through erosion has probably provided the impermeable basin seal retarding water loss through the sandy glacial drift beneath. The irregular fluctuations of level for which the lake has been known in the past may well be explained by partial breaching of this seal and its subsequent restoration. For example, there was a long-continued decline between 1934 and the winter of 1950–1, when the level was restored by heavy snow and rain, and continued high through the ensuing summer. It is reasonable to suppose that the abnormal floods carried in sufficient peat and silt to bring back the basin seal to its former efficiency. The presence of such a seal is further attested by the phenomena observed when two aerial bombs dropped on the lake bank in 1941, and a flow of water past the bottoms of the craters and away from the lake created appreciable suction (Lind 1951).

In considering the normal Cheshire meres, exemplified by the last seven in Table 1, it may be noted that the two richest in salts, Pick and Budworth Meres, while occupying low land in the vicinity of the Northwich salt mines, exhibit ionic proportions very similar to those of the others. That is to say, they are rich in calcium bicarbonate, and show no sign of brine infiltration from the salt beds. Nevertheless, while the normal meres are strongly calcareous, the high proportions of sodium chloride, and especially of magnesium sulphate, mark them off from lakes owing their high ionic concentrations solely to their situation in limestone country. One of these, Sunbiggin Tarn in the Lake District, which closely resembles the limestone lakes of the Siljan district in Sweden (Lohammar 1938), is represented in Table 2.

The Cheshire waters are of course much richer in all major ions than the normal non-calcareous Lake District waters (Mackereth 1957). These lie on much harder and less easily weathered substrata, and in an area with not only a great excess of rainfall over evaporation, but also strong relief, both factors favouring rapid transport of salts to the sea and low ionic concentrations in the lake waters.

A comparison of the Cheshire meres with the average fresh water of the world (see Tables 1 and 2) shows the former to be about twice as concentrated, and enriched especially in chloride and sulphate, to a lesser extent in magnesium. There is also a striking difference in the balance of sodium and chloride. In the Cheshire series the two are almost equivalent, pointing to a marine origin; whereas in the world average water the proportion of sodium is distinctly greater than that of chloride, the excess no doubt originating in rock-weathering of aluminosilicate minerals.

Examination of the ratios of sodium to

chloride in the individual mere waters raises further points of interest. The Sandiway ratio, 0.82, is close to that of sea water, 0.85, and hence probably close to the average ratio in rain. (The Lake District rain ratio is in fact 0.90, but being a spring-autumn value may be a little high due to dust supply of sodium; unpublished winter analyses show an opposite and compensatory tendency toward a ratio lower than in sea water, owing probably to atmospheric pollution by industrial hydrochloric acid.) Oak Mere, Whitegate New Pool, Hatch Mere, and Budworth Pool show a decline to between 0.76 and 0.78, which may perhaps result from an exchange of sodium, abundant in rain, for the divalent metal cations adsorbed in large quantities on soil colloids. In contrast, the four most concentrated waters (Rostherne, Tatton, Pick, and Budworth Meres) show distinctly higher ratios, varying from 0.91 to 1.01. These meres all lie more in the lowland than the first group, which is located near the edge of the Delamere Forest upland. Thus the relatively high sodium/chloride ratios may still reflect some slight contribution of sodium (probably adsorbed on soil colloids) from either the former salt lakes or the later marine submergence of this district. The high total salt concentrations of the above four meres are also presumably connected with their more low-lying situation.

The richness of the Cheshire waters in salts other than calcium bicarbonate reflects the conditions in which the geological substratum underlying the meres was laid down. During the Triassic period when the Keuper marls were deposited the climate was extremely arid, and the Cheshire plain was, as now, very flat (Edmunds and Oakley 1947). Whereas under high rainfall most of the more mobile ions such as chloride and sulphate would be leached away and replaced by bicarbonate, excessive evaporation and impeded drainage at this time combined to produce highly saline soils in the lowlands, with the formation of salt lakes in the lowest-lying basins, as for example around Northwich. The concentration of salts by evaporation led at the same time to precipitation of calcium carbonate in the Keuper marl beds, which however are not highly calcareous but made up largely of clays mixed with quartz dust of wind-blown desert origin, and of tiny crystals of dolomite. Later, in Jurassic times, there was a long period of marine submergence. Under the much moister climatic conditions of more recent periods, most of the saline residues have been washed out of the surface layers of the Keuper deposits, and at present weathering of calcium carbonate in the marls presumably provides the major source of ions for the ground waters feeding the meres.

However, in sites like Oak Mere, and especially Sandiway, where local irregularities of upland topography seal off a basin from ground water supply and leave it largely dependent upon runoff, the supply of calcium bicarbonate is greatly reduced, since only the uppermost horizons of soil, subject to the maximum degree of leaching, are percolated by the inflowing rainfall. It is no doubt this physiographic situation which is primarily responsible for the biological peculiarities of Oak Mere, so different in character from the other meres of the Cheshire plain.

A last point to be remarked is the comparative poverty of the Cheshire waters in silica as compared with the world average water. The Cheshire average of about 4 ppm SiO_2 is roughly comparable with levels in the much more dilute Lake District waters. A likely explanation is that in the Cheshire district leaching has not progressed to an advanced stage, and only the more mobile elements are being removed in quantity. Although much of the chloride and sulphate has gone from the surface soils, and bicarbonates are now accompanying the metal cations on their way seaward, the aluminosilicates have probably not yet suffered severe attack.

REFERENCES

Boyd, A. W. 1951. Notes on the natural history of Oakmere. II. Notes on the water birds. Mem. Manchester Lit. Phil. Soc., **92:** 10-11.

Conway, E. J. 1942. Mean geochemical data in relation to oceanic evolution. Proc. R. Irish Acad., Ser. B, **48:** 119-159.

EDMUNDS, F. H., AND K. P. OAKLEY. 1947. The Central England District. Handbooks on the Regional Geology of Great Britain, H.M.S.O., London, 2nd ed., 80 pp.

GALLIFORD, A. L. 1954. Two lakes of Delamere Forest—an ecological contrast. Proc. Liverpool Nat. Fld. Cl., pp. 21–26.

GORHAM, E. 1955. On the acidity and salinity of rain. Geochim. et Cosmoch. Acta, **7:** 231-239.

GORHAM, E. 1956. The chemical composition of some waters from the Moor House nature reserve. J. Ecol., **44:** 377-384.

LIND, E. M. 1944. The phytoplankton of some Cheshire meres. Mem. Manchester Lit. Phil. Soc., **86:** 83–105.

LIND, E. M. 1951. Notes on the natural history of Oakmere. I. Vegetation of the exposed shore, 1950. Mem. Manchester Lit. Phil. Soc., **92:** 1–9.

LIND, E. M., AND A. L. GALLIFORD. 1952. Notes on the plankton of Oakmere, Cheshire. Naturalist, Lond., pp. 99–102.

LOHAMMAR, G. 1938. Wasserchemie und höhere Vegetation schwedischer Seen. Symb. Bot. Upsaliens., **3:** 1–252.

MACAN, T. T., AND E. B. WORTHINGTON. 1951. Life in Lakes and Rivers. Collins, London. 272 pp.

MACKERETH, F. J. H. 1957. Chemical analysis in ecology illustrated from Lake District tarns and lakes. I. Chemical analysis. Proc. Linn. Soc. Lond. In press.