IRRIGATION WATERS OF THE BUNDABERG AREA.

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SUMMARY.

The underground irrigation water supplies of the Bundaberg area have been divided into three classes based on the overlying geologic formation. The topography and the soil characteristics of the two principal land types below which the main water-bearing beds are located are briefly discussed.

A number of waters from each of the three geologic areas have been analysed and their compositions compared, particularly on the basis of ionic ratios.

Tables of typical irrigation plant data are appended.

INTRODUCTION.

The very large and rapid extension of irrigation of sugar cane crops in the Bundaberg area since 1932 made a study of water quality in that district desirable. Water analyses performed during a period of over 40 years indicated wide extremes in mineral content, but no systematic study of the quality of the various water-bearing beds had been attempted prior to the work reported here.

The Bundaberg cane-growing area comprises five sugar mill districts with an average annual harvestable area of approximately 26,000 acres. The mill areas follow the basins of the Burnett, Elliott, and Kolan Rivers, with the major cane-producing areas concentrated within 20 miles of the sea coast. The soil types are sharply defined and are found to have an important bearing on the quality of the subterranean water. The Woongarra basaltic red loam has been longest cultivated and is the most important of the district's sugar cane soils. Next in importance is the reddish sandy forest type, while the recent alluvial soils of the Burnett and Kolan Rivers are third in area cultivated. A number of sub-types of lesser importance agriculturally have also been defined (King, 1935).

As early as 1906, Maxwell listed partial analyses of 194 waters from the Woongarra area in order of their content of total solids and salt (sodium chloride), but no reference was made to the relative amounts of the various ions present. At this period, following the 1901-03 drought, interest in irrigation was aroused, but such plants as were installed were not continued in operation. Most of the waters discussed by Maxwell were samples from wells not being used for irrigation, and there is nothing to indicate that they were representative of extensive water supplies.

The remarkable success in irrigating cane attained on large plantations at Bingera and Fairymead after the 1932 drought led to the rapid installation of a large number of individual irrigation plants throughout the district, pumping in the main from subterranean supplies. By 1947 there was estimated to be 177 individually owned plants operating, of which 152 were pumping from underground supplies. The remaining 25 plants pumped from either the Burnett or the Kolan River.

Basaltic formations frequently yield valuable supplies of water to wells and boreholes, though where they are very thick the water table may lie at a great depth. Water boring results in basaltic areas in Transvaal (Dixey, 1931) showed that for a total of 258 bores, with a mean depth of 138 feet, the average depth of water was 90 feet, rising to 50 feet, and the average yield was 26,500 gallons per day. The water occurred in joint openings and in the zones of vesicular and fragmental material lying between successive lava flows. Between the flows there was frequently much soil and decomposed rock due to weathering of the earlier flow prior to the outpouring of the succeeding one. Owing to the numerous open joints, basalt takes in surface waters very readily. In the Woongarra formation, however, water for irrigation on a reasonable scale is not obtainable from the basalt despite the 100-feet thickness encountered at some locations. A flow of 26,500 gallons per day—as quoted above—would be quite inadequate for even small-scale sugar cane irrigation, this amount per hour being a normal requirement. Irrigation wells and bores which have been developed on this formation have invariably gone right through the basalt into the sandy and gravelly water-bearing drifts below, which are part of the fresh-water sediments of the Burrum series of Cretaceous age (Bryan and Massey, 1926).

The number of successful large-scale irrigation installations on this basaltic area is small, but indications are that more extensive water-bearing beds exist, though their exploitation may be costly. The largest individual plant is a 12-inch one, but in the same locality, around the Qunaba-Spring Hill section, several large plants have been operating successfully for over 10 years. This is the area from which most water is being pumped in the Woongarra, but isolated plants to the south, east, and west of The Hummock suggest that good water-bearing drifts exist in these sections also. In every case the large water supply is below the basalt, though extensive seepage through open joints is usually encountered when sinking wells. No doubt this percolation of water through varying thicknesses of igneous formation has an influence on the composition of the water, the higher calcium and magnesium content of the sub-basaltic waters conforming to what might be expected from a highly basic rock.

The sub-forest water supplies, particularly those of the South Kalkie-Alloway-Clayton belt, are much more uniform in depth and distribution. The topography of the country is generally flat, and the depth at which water is encountered is, allowing for surface inequalities and variation in water-table level at time of drilling, remarkably constant. There is little doubt that a water-bearing drift of considerable area underlies this section of the Burrum series, as in more than 100 bores in this small cane-growing locality water-bearing material has been encountered at approximately a constant depth. The fact that ample supplies could not be pumped from some of the bores put down is not an indication of absence of a so-called "stream," but merely means that a section of drift with low permeability had been encountered. In any sedimentary formation the particle size of the sediments varies from point to point, and the rate of flow of water through the sediments varies accordingly. Examination of the "draw-down" figures in Table 8 shows that a high degree of freedom exists in these sub-forest drifts, since the water level sinks only 1 to 4 feet in most cases with a pump output of up to 65,000 gallons per hour. The capacity of this water-bearing bed was shown during the severe drought of 1946, when the demand on irrigation plants was at least double that of a normal year. The static water level fell, on an average, 5 or 6 feet throughout the area, but as there is an average of 30 feet depth of water-bearing drift this fall was not considered a serious one in terms of depletion of water supply.

The sub-alluvial water supplies have, with the exception of the large-scale installations on Fairymead Plantation, received less attention than those in the Woongarra and forest areas. During drought periods, however, a considerable number of bores have been sunk with varying degrees of success. On the Burnett River no uniformity in depth or type of water-bearing material has been experienced, and this is in line with general knowledge of other recent alluvial deposits. Layers of silty or clayey material at different depths divide the water-bearing strata and no unbroken gravel layers of considerable depth appear to have been encountered. The presence of clay seams restricts water flow into the spears and reduces the body of water available. There is also evidence of direct communication with the tidal waters of the Burnett River, as discussed under water quality. Rather similar conditions obtain on the Kolan River, though the attempted development of irrigation there has been less extensive.

The Burnett River supplies a considerable volume of irrigation water for cane-growing in the Bingera and adjacent areas. The weiring of this stream in 1934 impounded a large quantity of good quality water for this purpose. Bingera Plantation and a considerable number of individual farmers pump from the river throughout the drier months of the year, and so extensive is the Burnett River catchment area that even during the 1946 drought the water level did not shrink to a dangerous point. Below the weir the river is tidal and no water is pumped for irrigation. Several small or medium-sized pumps operate on the Kolan River, which is not weired, but all are above the limit of tidal influence.

The data discussed in this paper were obtained principally during 1946, when pumping was at its maximum and when quality might be expected to be at its worst. Many of the waters were subjected only to partial analysis, but a complete analysis was made of a true cross section of the various water types. Methods used were, with minor variation, those described by Cassidy (1944), except that potassium was determined by the cobalti-nitrite method of Piper (1942).

WATER QUALITY.

The composition and the quality of ground waters vary greatly from place to place and often within short distances. The variations are due to differences in the chemical composition of the rocks through which the waters have percolated, to the type of underground circulation, and to the period of contact with rocks and soils. In comparing the sub-basalt and sub-forest waters in the Bundaberg district, the differences in quality are very apparent. The former type, because of their location below a thick basalt layer, would be expected to be adulterated by percolating water which, during its passage through cracks and fissures in the rock, leaches out soluble mineral material. The relatively high Ca, Mg, Na, K, Cl SO_4 and HCO_3 content is suggestive of such contamination. By contrast the sub-forest waters are low in mineral matter, the overlying 30 or 40 feet of sandy sediments contributing little soluble mineral material under the influence of leaching. This overlying soil is known to be deficient in soluble bases and has, in fact, to be periodically limed to correct the undesirable concentration of hydrogen ions which develops under natural conditions.

Table 1 (a).

SUB-BASALTIC WATERS BEING USED FOR IRRIGATION.

No.	Farm Source.	Chlorides as NaCl.	Total Alkalinity.	Total Hardness.	Free Alkali.
		gr.p.g.	gr.p.g.	gr.p.g.	gr.p.g.
1	J. Lutz, Sandhills Road	102·3	4·2	52·8	..
2	G. Fabricato, Springfield Road	3·3	1·9	2·1	..
3	Sugar Experiment Station	3·3	5·6	4·2	1·4
4	J. Chappell, Burnett Heads	8·2	9·6	1·8	7·8
5	Qunaba Irrigation	29·5	11·9	15·1	..
6	Qunaba Mill Supply..	88·8	..	49·7	..
7	Qunaba Mill Supply..	78·5	13·7	43·2	..
8	R. G. Strathdee, Burnett Heads	44·2	13·9	24·5	..
9	W. J. Zunker, Qunaba	13·9	12·6	8·2	4·4
10	F. Zielke, Ashfield Road	72·1	7·2	29·2	..
11	Jorgensen Bros., Burnett Heads	28·6	10·2	19·3	..
12	Spring Hill Plantation	35·6	10·9	19·6	..
13	W. C. Stockwell, Springfield	22·4	1·9	7·7	..
14	W. Slane, Qunaba	17·6	10·7	10·7	..
15	T. Young, Burnett Heads	19·4	9·8	14·0	..
16	R. M. Hurley, Sandhills Road	17·1	11·0	12·2	..
17	H. S. Skyring, Wawoon	9·9	1·9	3·9	..
18	G. C. C. Maughan, Gahan's Road	86·2	3·2	49·0	..
19	A. W. Bates, South Kolan	26·5	3·0	1·9	1·1
20	J. C. Maughan, Seaview Road	231	13·7	36·6	..

The sub-alluvial waters being used for irrigation are too few for comparison with the other types, but the large number which have been found unsuitable for irrigation indicates contamination with tidal river waters.

The partial analysis figures given in Table 1 (a) indicate the composition of the waters being pumped from drift beds below the Woongarra and Hill End basaltic formations, while Table 1 (b) contains similar figures for waters in the same areas not yet being pumped extensively. The data given in these tables suggest that the waters are not of good quality, though, as will be mentioned later, total salt and chloride content is not the best criterion of water quality. Sodium chloride, calculated from chlorine, averages about 50

Table 1 (b).

SUB-BASALTIC WATERS NOT BEING EXTENSIVELY PUMPED.

No.	Farm Source.	Chlorides as NaCl.	Total Alkalinity.	Total Hardness.	Free Alkali.
		gr.p.g.	gr.p.g.	gr.p.g.	gr.p.g.
21	A. R. Greenshill, Windermere Road ..	44·0	17·2	35·4	..
22	A. C. Zischke, St. John's Road	16·4	7·9	12·9	..
23	B. Dargusch, Cattermull Avenue	36·0	17·5	27·3	..
24	T. W. Sharp, Barolin	12·2	1·6	5·3	..
25	T. W. Sharp, Barolin	54·8	11·2	32·2	..
26	W. H. Wessel, Seaview Road	113	25·9	66·2	..
27	R. Volzke, Rubyanna Road	104	14·0	57·0	..
28	C. Braddock Pemberton	5·7	9·6	4·2	..
29	C. Wittkopp, Sandhills Road	115·5	6·5	66·9	..
30	E. Galea, Springfield	24·9	15·2	26·8	..
31	G. Mangano, Barolin Road..	93·3	9·3	33·6	..
32	F. Faulkner, Burnett Heads	58·4	15·4	34·0	..
33	K. Young, Qunaba	102·8	14·9	30·6	..
34	K. Young, Qunaba	89·0	15·2	25·7	..
35	J. Donovan, Sandhills Road	60·0	14·9	41·1	..
36	K. Rasmussen, Hummock	12·7	9·8	3·7	6·1
37	H. J. Strathdee, Burnett Heads	35·8	21·7	13·5	..
38	G. H. Baldry, Burnett Heads	53·1	12·9	33·0	..
39	H. Killer, Sandhills Road	39·3	21·9	24·7	..

grains per gallon and attains well over 100 in some areas. The water of highest salt content—viz., 231 grains per gallon—is being used for irrigating cane, but it is too early to say whether any ill-effects will follow its continued use. The small proportion of these waters carrying free alkali is characteristic of the subterranean supplies of the district.

Table 2 gives partial analyses of 37 waters from the drift beds underlying the sandy loam forest lands of the district. These lands are farmed intensively in South Kalkie, Alloway, Oakwood, and Gooburrum, and it is in these areas that irrigation has advanced more than elsewhere. The waters are very low in both monovalent and divalent ions and on this basis can be regarded as of very high quality. The very low alkalinity indicated in the majority of these waters is probably only a measure of the amount of acid required to discharge the alkaline colour of the methyl orange. Boiling with phenolphthalein for a considerable period does not develop any pink coloration and indicates the absence of bicarbonates of calcium and magnesium.

The underground waters of the alluvial lands on the Burnett and Kolan rivers are shown by Table 3 to have a much higher salt content and alkalinity than those under the basaltic and forest lands. All of these waters are from

Table 2.

Sub-forest Waters being Used for Irrigation.

No.	Farm Source.	Chlorides as NaCl.	Total Alkalinity.	Total Hardness.	Free Alkali.
		gr.p.g.	gr.p.g.	gr.p.g.	gr.p.g.
40	J. T. Thiele, South Kalkie	2·5	0·5	1·2	..
41	S. Vecchio, South Kalkie	2·5	0·4	0·7	..
42	H. Petterson, South Kalkie	3·3	0·4	0·7	..
43	V. Parisi, South Kalkie	7·62	0·5	0·9	..
44	H. Rehbein, South Kalkie	8·5	0·4	1·9	..
45	G. Marano, South Kalkie	6·2	0·4	1·2	..
46	W. T. Hopkins, South Kalkie	3·9	0·2	1·2	..
47	P. F. Plath, South Kalkie	3·2	0·2	1·6	..
48	R. Lerch, South Kalkie	4·2	0·7	0·5	0·2
49	C. E. Tesch, South Kalkie	2·5	0·4	0·7	..
50	W. Truscott, South Kalkie	2·5	0·4	0·7	..
51	W. Truscott, South Kalkie	3·3	0·4	1·1	..
52	F. Jacobsen, South Kalkie	9·2	0·2	0·7	..
53	H. Gollschewsky, South Kalkie	1·9	0·4	1·4	..
54	A. Courtice, South Kalkie	5·3	0·5	1·8	..
55	F. J. Walk, South Kalkie	10·4	0·2	2·3	..
56	H. Lerch, South Kalkie	10·2	1·1	2·3	..
57	S. Marano, South Kalkie	7·2	0·4	2·3	..
58	Thiele Bros., Alloway	4·9	0·9	1·6	..
59	W. Douglas, Alloway	4·4	0·7	0·5	0·2
60	B. Anderson, Alloway	4·4	0·9	0·7	0·2
61	H. D. Buss, Maryborough Road	5·6	1·1	1·6	..
62	G. Torrisi, Kepnock	4·9	0·4	1·4	..
63	L. Kent, Kepnock	5·8	0·5	2·3	..
64	A. F. Lutz, Clayton	9·9	2·5	3·5	..
65	A. Zielke, Kepnock	2·3	1·1	0·9	0·2
66	A. Jacobsen, Gooburrum	3·3	0·4	0·7	..
67	W. G. Batchler, Gooburrum	3·3	0·4	1·1	..
68	E. A. Nielson, Gooburrum	4·1	0·4	1·1	..
69	B. H. Lehmann, Gooburrum	4·1	0·4	1·1	..
70	S. N. Gear, Gooburrum	2·5	0·4	0·4	..
71	B. J. Pegg, Oakwood	2·8	0·4	1·8	..
72	M. J. Hynes, Oakwood	1·9	1·1	0·9	0·2
73	Chase Bros., Gooburrum	2·8	0·2	0·7	..
74	Stitt and Sons, Sharon	3·9	1·8	0·4	1·4
75	Batchler and Rudder, Gooburrum	3·2	0·7	0·2	0·5
76	Warneminde and Cochrane, Gooburrum	4·6	0·2	2·6	..

farms on the tidal reaches of the rivers. Tests carried out on several such locations showed an increase in chlorine with continued pumping, strongly indicative of a connexion between the subterranean water-bearing bed and the tidal river. Boring on many similar properties also indicated small water beds of good quality at one depth and a much larger water bed of poor quality at a deeper level, the two beds being separated by a heavy clay stratum. Such a development at Millbank on the Burnett River, where the stream makes a sharp bend, suggests that part of the tidal water cuts across under this recent alluvial deposit and adulterates the subterranean water.

Cassidy (1944) has discussed ionic ratios of Queensland coastal waters and compared these ratios with those of sea water and the great rivers of the world. Similar ionic ratios for the Bundaberg district waters are shown in Table 6. The Na/Cl ratio is reasonably constant for both sub-basaltic and sub-forest waters, though there is an indication that it is slightly higher in

Table 3.

SUB-ALLUVIAL WATERS.

No.	Farm Source.	Chlorides as NaCl.	Total Alkalinity.	Total Hardness.	Free Alkali.
		gr.p.g.	gr.p.g.	gr.p.g.	gr.p.g.
77	A. Scott, Millbank*	100·0	8·9	44·1	..
78	A. Scott, Millbank	36·0	16·2	6·7	9·5
79	A. W. Nielsen, Millbank	7·4	0·7	3·5	..
80	D. W. Clarry, Moorlands	88·0	5·1	19·3	..
81	W. H. Anderson, Moorlands	28·0	5·3	10·5	..
82	A. Toft, North Bundaberg	86·8	4·9	27·0	..
83	V. E. Tallon, North Bundaberg	52·4	3·5	39·9	..
84	J. Buchbach, Tegege*	138·0	23·6	28·0	..
85	J. Buchbach, Tegege*	47·5	10·7	13·7	..
86	S. E. Toft, Millbank	5·0	0·9	2·8	..
87	R. Geddes, Waterview	44·2	8·9	15·4	..
88	L. See Chin, North Bundaberg	28·6	0·5	19·6	..
89	J. Buchbach, Tegege	25·0	7·0	8·1	..
90	G. Broom, Avondale*	77·0	6·3	8·1	..
91	J. C. Twyford, Avoca	27·9	6·5	8·4	..
92	J. C. Twyford, Avoca (deep)*	176·5	6·2	36·9	..
93	W. Grimes, Tegege	9·8	3·0	4·9	..
94	K. P. Knudsen, Bonna	11·5	13·8	8·4	5·4
95	H. Wallace, New Bundaberg*	176·5	18·2	30·3	..
96	C. Rowland, Burnett Heads*	160·0	14·7	36·1	..
97	A. Hicks, Burnett Heads*	127·1	28·8	18·9	..
98	A. Ness, Rubyanna*	838·5	..	..	..
99	A. Ness, Rubyanna*	978·0	..	..	..
100	A. Ness, Rubyanna*	531·0	..	..	..
101	C. Rowland, Burnett Heads*	171·0	..	..	..
102	C. Rowland, Burnett Heads*	166·5	..	..	..
103	C. Rowland, Burnett Heads*	181·5	..	..	..

* Not being used for irrigation.

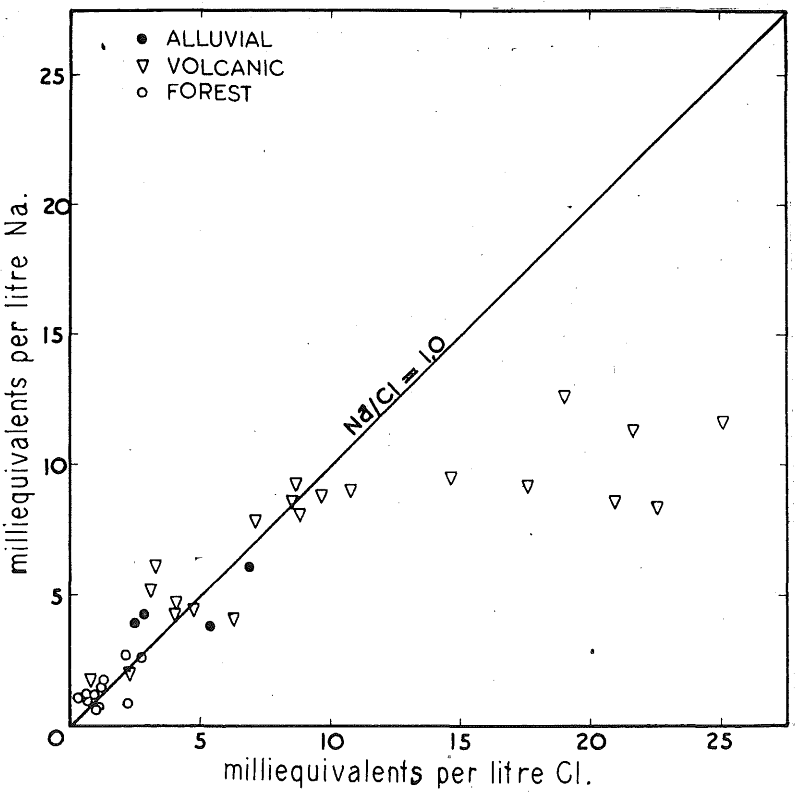


Figure 1.

Scatter diagram of Na/Cl ionic ratios for 36 waters.

the latter type. This is illustrated in Fig. 1, where the ionic concentrations of Na and Cl are plotted against each other. The Ca/Mg ratio is higher in the sub-forest waters, but the $\frac{Ca+Mg}{Na+K}$ and the HCO_3/Cl ratios are much higher in the sub-basaltic types. Some of these ratios diverge rather widely from those found by Cassidy for Queensland coastal waters; the divergence serves to indicate the variable quality of water supplies within that belt. All ratios, however, fall between those published for sea water on the one hand and the world rivers on the other and suggest the influence of cyclic salt.

In Table 4 are presented analyses of a cross section of the three type waters being used extensively in irrigation. The concentrations of the various ions are shown in milliequivalents per litre; in Table 5 they are expressed as a percentage of the total ion content. Major differences indicated by Table 4 are the much higher concentration of all ions in the sub-basalt type than in the sub-forest type and the intermediate position occupied by the sub-alluvial and river waters. The rather high Na concentration in the sub-basalt waters is not dangerous when the soil type and the ratio of divalent to monovalent ions are considered. The red basaltic loam is a very deep, well-drained, highly

Table 4.

ANALYSIS OF VARIOUS WATERS, SHOWING IONS IN MILLIEQUIVALENTS PER LITRE.

No.	Farm or Other Source.	Cl^-	HCO_3^-	$SO_4^{=}$	Ca^{++}	Mg^{++}	Na^+	K^+
	Basaltic Type Samples							
6	Qunaba Mill	26·32	4·13	3·57	4·29	10·58	12·42	·13
7	Qunaba Mill	19·15	3·21	3·08	5·54	8·66	12·65	·26
5	Qunaba Irrigation	7·20	2·79	1·54	1·36	3·20	7·85	·20
11	Jorgensen Bros., Burnett Heads	6·99	2·39	1·37	1·74	4·67	5·74	·18
12	Spring Hill Plantation.. ..	8·67	2·55	1·68	1·66	4·10	8·67	·19
8	R. G. Strathdee, Burnett Heads	10·80	3·26	2·64	5·90	2·08	8·98	·21
15	T. Young, Qunaba	4·73	2·30	1·27	1·06	3·30	4·55	·19
14	W. Slane, Qunaba	4·28	2·51	1·10	1·00	2·37	4·68	·20
16	R. M. Hurley, Sandhills Road	4·17	2·58	1·28	1·18	3·23	4·48	·17
10	F. Zielke, Ashfield Road ..	17·60	1·69	2·14	2·52	10·74	9·32	·20
18	G. C. C. Maughan, Gahan's Road	21·01	0·74	2·57	4·32	9·84	8·64	·18
3	Sugar Experiment Station ..	0·80	1·31	0·34	0·60	0·58	1·79	·18
17	H. Skyring, Wawoon	2·42	0·45	0·68	0·40	0·97	2·01	·07
20	J. C. Maughan, Seaview Road	56·32	3·18	3·05	2·60	9·34	53·63	·18
13	W. C. Stockwell, Springfield ..	5·46	0·44	0·27	0·62	1·87	3·88	·07
19	A. W. Bates, South Kolan ..	6·48	0·70	0·14	0·42	0·93	4·09	·06
31	G. Mangano, Barolin Road ..	22·75	2·17	2·46	2·70	10·03	8·41	·21
	Forest Type Samples							
50	W. Truscott, South Kalkie ..	0·60	0·08	0·20	0·05	0·36	1·27	·07
49	C. E. Tesch, South Kalkie ..	0·60	0·08	0·20	0·40	0·22	1·11	·07
58	Thiele Bros., Alloway	1·18	0·21	0·16	0·48	0·18	1·04	·08
60	B. Anderson, Alloway ..	1·07	0·20	0·03	0·18	0·43	0·91	·07
48	R. Lerch, South Kalkie ..	1·02	0·16	0·12	0·30	0·29	0·96	·06
104	M. W. Hiscock, Alloway ..	1·02	0·16	0·55	0·20	0·29	0·89	·08
55	F. J. Walk, South Kalkie ..	2·53	0·04	0·21	0·10	0·61	2·65	·07
52	F. Jacobsen, South Kalkie ..	2·31	0·04	0·20	0·25	0·31	1·96	·09
67	W. G. Batchler, Gooburrum ..	0·80	0·08	0·52	0·05	0·18	1·01	·07
70	S. Gear, Gooburrum	0·62	0·08	0·34	0·18	0·22	1·13	·05
107	Waimea Plantation	1·24	0·12	1·03	0·20	0·32	1·79	·06
62	G. Torrisi, Kepnock	1·20	0·08	0·24	0·16	0·32	1·34	·07
63	L. Kent, Kepnock	1·41	0·12	0·23	0·17	0·31	1·72	·06
105	Bundaberg North Water Supply	2·25	0·23	0·96	0·36	0·82	2·78	·06
	Alluvial Type Samples							
94	K. P. Knudsen, Bonna ..	2·80	3·23	1·06	1·26	1·58	4·23	·06
91	J. C. Twyford, Avoca	6·80	1·52	0·51	0·78	2·22	6·19	·05
106	Burnett River (above weir) ..	5·41	1·97	0·98	1·20	2·51	3·94	·02

flocculated soil containing upwards of 15 m.e. per cent. of total replaceable bases, of which Ca and Mg constitute over 90 per cent. It is also shown in Table 6 that, despite the high Na concentration in these waters, the Ca + Mg/Na + K ratio averages ·86 and that only two of the waters have a ratio below ·5.

Present day opinion on irrigation water quality tends to rely more on this ratio of divalent to monovalent ions than on the actual concentration of

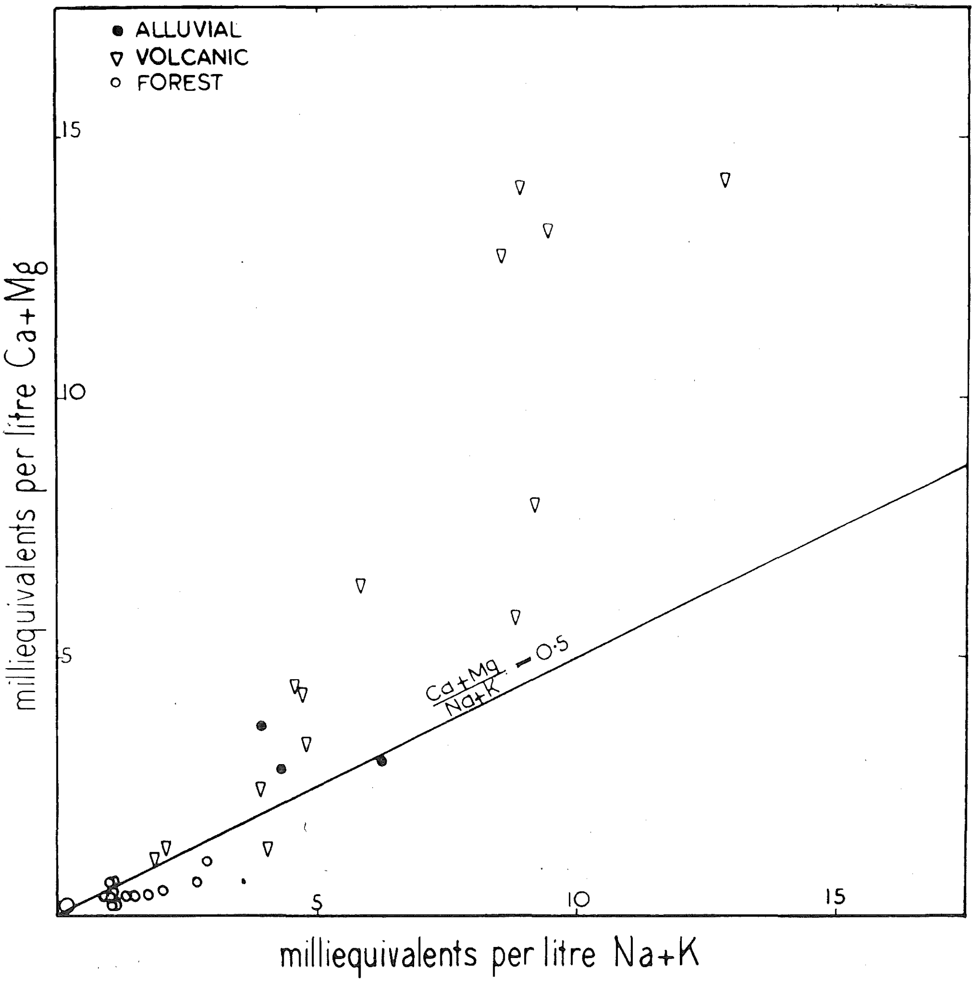


Figure 2.

Scatter diagram of Ca + Mg/Na + K ionic ratios for 30 waters.

the individual elements. Cassidy has discussed this ratio as a "Figure of Merit" of an irrigation water, since it gives a measure of the likely base exchange reaction with the soil. An undesirable physical condition of the soil is readily induced by the use of water with a low ratio of divalent to monovalent ions, but so long as the ratio remains above 0·5 the divalent bases appear to exert a beneficial influence in retaining good physical condition. Very broadly, the higher this ratio the better the water quality and, within ill-defined limits, the ratio is taken as the true quality index irrespective of the actual amounts of the ions present.

The "Figure of Merit" (f) for the sub-basalt waters in Table 6 is in the majority of cases well above 0·5 and exceeds unity in several. Of the two waters where f is below 0·5, one has been used for 13 years without apparent change in the physical condition of the soil; the other has been in use for too short a period to gauge its effect.

Table 5.

ANALYSIS OF VARIOUS WATERS, SHOWING IONS AS PERCENTAGE OF TOTAL MILLIEQUIVALENTS.

No.	Farm or Other Source.	(Per cent of Total Milliequivalents.)						
		Cl^-	HCO_3^-	$SO_4^{=}$	Ca^{++}	Mg^{++}	Na^+	K^+
	Basaltic Type Samples							
6	Qunaba Mill	42·84	6·72	5·81	6·98	17·22	20·22	·21
7	Qunaba Mill	36·44	6·11	5·86	10·50	16·47	24·07	·49
5	Qunaba Irrigation	29·82	11·55	6·37	5·63	13·25	32·51	·82
11	Jorgensen Bros., Burnett Heads	30·28	10·39	5·93	7·53	20·23	24·87	·78
12	Spring Hill Plantation.. ..	31·50	9·26	6·08	6·03	14·89	31·50	·69
8	R. G. Strathdee, Burnett Heads	31·88	9·62	7·79	17·41	6·14	26·51	·62
15	T. Young, Qunaba	27·18	13·21	7·29	6·09	18·96	26·09	1·09
14	W. Slane, Qunaba	26·51	15·55	6·81	6·19	14·67	28·99	1·23
16	R. M. Hurley, Sandhills Road	24·40	15·09	7·48	6·90	18·89	26·21	·99
10	F. Zielke, Ashfield Road ..	39·81	3·82	4·84	5·70	24·29	21·08	·45
18	G. C. C. Maughan, Gahan's Road	44·41	1·56	5·43	9·13	20·80	18·26	·38
3	Experiment Station	14·28	23·39	6·07	10·71	10·35	31·96	3·03
17	H. Skyring, Wawoon	34·57	6·42	9·71	5·71	13·85	28·71	1·00
20	J. C. Maughan, Seaview Road..	43·89	2·47	2·37	2·02	7·27	41·80	·14
13	W. C. Stockwell, Springfield ..	43·29	3·48	2·14	4·91	14·82	30·76	·55
19	A. W. Bates, South Kolan ..	50·54	5·30	1·09	3·27	7·25	32·00	·46
31	G. Mangano, Barolin Road ..	46·68	4·45	5·04	5·54	20·58	17·25	·43
	Forest Type Samples							
50	W. Truscott, South Kalkie ..	22·81	3·04	7·60	1·90	13·68	48·28	2·66
49	C. E. Tesch, South Kalkie ..	22·38	2·98	7·46	14·92	8·20	41·41	2·61
58	Thiele Bros., Alloway	35·43	6·30	4·80	14·41	5·40	31·23	2·40
60	B. Anderson, Alloway ..	37·02	6·92	1·03	6·22	14·87	31·48	2·42
48	R.Lerch, South Kalkie ..	35·05	5·49	4·12	10·30	9·96	32·98	2·06
104	M. W. Hiscock, Alloway ..	31·97	5·01	17·24	6·26	9·09	27·89	2·50
55	F. J. Walk, South Kalkie ..	40·74	·64	3·38	1·61	9·82	42·67	1·12
52	F. Jacobsen, South Kalkie ..	44·76	·77	3·87	4·84	6·00	37·98	1·74
67	W. G. Batchler, Gooburrum ..	29·52	2·95	19·18	1·84	6·64	37·26	2·58
70	S. Gear, Gooburrum	23·66	3·05	12·97	6·87	8·39	43·12	1·90
107	Waimea Plantation	26·05	2·52	21·64	4·20	6·72	37·61	1·26
62	G. Torrisi, Kepnock	35·18	2·05	7·03	4·69	9·38	39·29	2·05
63	L. Kent, Kepnock	35·07	2·98	5·72	4·22	7·71	42·78	1·49
105	Bundaberg North Water Supply	30·16	3·08	12·86	4·82	10·99	37·26	·80
	Alluvial Type Samples							
94	K. P. Knudsen, Bonna ..	19·65	22·71	7·45	8·86	11·11	29·80	·42
91	J. C. Twyford, Avoca	37·63	8·41	2·82	4·31	12·23	34·25	·27
106	Burnett River (above weir) ..	33·74	12·28	6·11	7·48	15·65	24·57	·12

The *f* value of the sub-forest waters is not so favourable, averaging only 0·39 for the 13 samples fully analysed. However, since the total of the four ions averages only 2 milliequivalents per litre, the possibility of any appreciable deterioration in soil structure due to watering is slight. Further, the soils are well drained and the periodic lime applications which are made to counteract soil acidity also guard against the development of too high a proportion of Na in the base exchange complex. Observant farmers state that they are

Table 6.

IONIC RATIOS OF BUNDABERG AND OTHER WATERS.

No.	Farm or Other Source.	Na/Cl	Ca/Mg	$\frac{Ca+Mg}{Na+K}$	HCO_3/Cl
6	Qunaba Mill	0·47	0·41	1·18	0·16
7	Qunaba Mill	0·66	0·64	1·10	0·17
5	Qunaba Irrigation	1·09	0·42	0·57	0·39
11	Jorgensen Bros.	0·82	0·37	1·08	0·34
12	Spring Hill Plantation	1·00	0·40	0·65	0·29
8	R. G. Strathdee	0·83	2·80	0·87	0·30
15	T. Young	0·96	0·32	0·92	0·49
14	W. Slane	1·09	0·42	0·70	0·59
16	R. M. Hurley	1·08	0·37	0·95	0·62
10	F. Zielke	0·53	0·23	1·39	0·09
18	G. C. C. Maughan	0·41	0·44	1·61	0·04
3	Sugar Experiment Station	2·35	1·04	0·59	1·64
17	H. S. Skyring	0·83	0·41	0·66	0·19
31	G. Mangano	0·82	0·26	1·48	0·10
13	W. C. Stockwell	0·71	0·33	0·63	0·08
19	A. W. Bates	0·63	0·45	0·32	0·11
20	J. C. Maughan	0·95	0·28	0·22	0·05
50	W. Truscott	2·11	0·14	0·30	0·14
49	C. E. Tesch	1·80	1·90	0·52	0·14
48	R. Lerch	0·94	1·00	0·57	0·16
104	M. W. Hiscock	0·87	0·69	0·50	0·16
60	B. Anderson	0·85	0·42	0·62	0·19
58	Thiele Bros.	0·88	2·70	0·59	0·18
55	F. J. Walk	1·05	0·16	0·26	0·02
52	F. Jacobsen	0·85	0·83	0·27	0·02
67	W. G. Batchler	1·27	0·28	0·21	0·10
70	S. N. Gear	1·83	0·84	0·33	0·13
107	Waimea Plantation	1·44	0·63	0·28	0·10
62	G. Torrisi	1·12	0·49	0·34	0·07
63	L. Kent	1·22	0·56	0·27	0·09
94	K. P. Knudsen	1·51	0·80	0·66	1·15
91	J. C. Twyford	0·91	0·35	0·48	0·22
106	Burnett River (above weir)	0·73	0·40	0·90	0·36
105	Bundaberg North Water Supply	1·24	0·44	0·42	0·10
	River Waters (World)	1·6	3·7	4·3	7·3
	Sea Water	0·85	0·2	0·27	0·005
	Average of some inland rivers	0·83	0·91	1·75	1·00
	Hawaiian Irrigation waters (average) ..	0·9	0·8	1·1	0·9

Table 7.

UNSUITABLE WATERS AWAY FROM TIDAL INFLUENCE.

No.	Farm or Other Source.	Chlorides as NaCl.	Total Alkalinity.	Total Hardness.	Free Acidity.
		gr. p.g.	gr. p.g.	gr. p.g.	
108	W. H. Grieving, Rosedale	440	18·7	76·3	..
109	W. E. A. Cross, Rosedale	390	13·1	75·6	..
110	W. J. Lucke, Kolan Road South	692	nil	71·0	3·85
111	W. J. Lucke, Kolan Road South	1,550	nil	89·6	1·58
112	E. Grills, Watalgan	541	39·7	60·6	..
113	C. W. Hood, Kolan Road South	869	nil	69·0	12·3
114	C. W. Hood, Kolan Road South	1,286	..	..	..
115	G. B. Pignat, Mullet Creek	991	nil	72·1	2·8
116	F. Hales, Rosedale	229	25·4	82·3	..
117	G. W. Moore, Kolan Road South	446	..	..	..
118	Snake Creek (Waterhole)	1,031	6·1	80·0	..
119	Bauer Bros., Watalgan	188	nil	37·5	2·1

noting a deterioration of the tilth of their forest soils after 10 or 12 years of irrigation, but this, if true, is more likely to be caused by a breakdown in crumb structure due to the alternate wetting and drying and the puddling of the wet soil by irrigators than by an increase in sodium in the clay fraction. The amounts of exchangeable sodium in irrigated and non-irrigated soils do not indicate any significant increase after years of watering.

In order to illustrate the inadvisability of judging an irrigation water on its total ionic content, the following brief account of tests carried out with No. 6 water on a red basaltic soil is given. The composition of the water, as given in Tables 1 (a) and 4 shows both chlorides and total solids to be very high. Five months after irrigation with this water a sample of soil was taken and analysed, and a sample from an adjacent non-irrigated field was also collected and analysed. Part of the sample of the irrigated soil was placed in a cylinder, given an artificial 20-inch irrigation with the water concerned, and analysed. A further sample from the irrigated field was taken after a fall of five inches of rain and analysed. The four analyses are given below.

Soil.	Replaceable Bases m.e. per 100 gms.			
	Ca.	Mg.	Na.	K.
No. 1 Irrigated for five months	32·9	13·1	1·05	0·43
No 2 Same as No. 1 but extra 20 ″ irrigation	33·3	12·5	1·2	0·35
No. 3 Same as No. 1 after 5″ rain	20·8	10·5	1·2	0·35
No. 4 Non-irrigated soil	13·8	5·9	0·59	0·16

Ca and Mg showed marked increases after five months irrigation, but the extra 20-inch irrigation did not alter the figures significantly. The leaching with 5 inches of rain, however, caused a considerable reduction in Ca and to a less marked extent in Mg. Na doubled with 5 months under irrigation and

Table 8.

Irrigation Plant Data in the Bundaberg Area*.

Name.	Address.	Depth to Drift.	Number and Size Spears.	Size and Type of Pump.	Depth to Static Water Level.	Draw-Down.	Engine H.P.	Pumping Capacity per Hour.
		Feet.		Inches.	Feet.	Feet.		Galls.
Sub-basaltic Irrigation Plants.								
A. W. Bates and Sons	South Kolan	71	No spears	7 ver.	25	5	40	40,000
J. Chappell	Burnett Heads	60	ditto	$\frac{5}{6}$ hor.	37	16	24	30,000
G. Fabricato	Pemberton	26	2 x 4 in.	4 ver.	40	2	10	16,000
Fairymead Sugar Co.	Springhill	..	3 x 6 in. + open 12 in. pipe	12 hor.	55	10	125	100,000
R. M. Hurley	Sandhills Road	72	nil	4 hor.	36	18	28	16,000
Jorgensen Bros.	Burnett Heads	95	nil	6 ver.	70	20	50	40,000
J. Lutz	Sandhills Road	91	nil	$\frac{3}{4}$ hor.	35	23	..	16,000
G. C. C. Maughan	Gahan's Road	36	2 x 4 in. / 1 x $2\frac{1}{2}$ in.	4 hor.	36	5	18	20,000
J. C. Maughan	"Fairfield"	40	nil	3 hor.	33	4	..	12,000
W. Shaw	Burnett Heads	88	1 x 5 in. / 1 x 6 in.	6 hor.	70	16	47	30,000
W. C. Stockwell (1)	Springfield	45	2 x 4 in.	4 hor.	27	6	14	13,000
W. C. Stockwell (2)	Springfield	..	3 x 3 in. / 1 x 2 in.	4 hor.	30	6	8	15,000
R. G. Strathdee	Burnett Heads	33	1 x 5 in.	4 her.	34	..	13	15,000
T. Young	Rubyanna	107	nil	6 ver.	66	12	44	40.000
F. Zielke	Ashfield Road	79	2 x 4 in.	$\frac{3}{4}$ hor.	64	..	17	18,000
Sub forest-land irrigation plants.								
B. Anderson	Alloway	56	5 x 3 in. to 5 in.	5 hor.	60	3	28	20,000
W. G. Batchler	Gooburrum	55	5 x 5 in.	7 hor.	30	7	34	55,000
Batchler and Rudder	Gooburrum	53	3 x 5 in.	6 hor.	27	5	31	45,000

Chase Bros.	Gooburrum	42	2 x 4 in. 1 x 2½ in.	4 hor.	50	1	18	16,000
W. Douglas	Coonarr Road	68	2 x 6 in. 2 x 4 in.	6 ver.	45	4	30	40,000
Fairymead Sugar Co.	Waimea	..	14 x 6 in.	12 hor.	16	..	125	100,000
A. Jacobsen	Maryborough Road	62	2 x 4 in.	$\frac{4}{5}$ hor.	63	2	30	20,000
A. Jacobsen	Gooburrum	75	3 x 4 in. 1 x 3 in.	5 hor.	36	3	19	20,000
F. Jacobsen	South Kalkie	30	3 x 6 in.	7 hor.	28	4	34	65,000
H. Lerch	South Kalkie	55	2 x 4 in.	5 hor.	40	5	15	25,000
R. Lerch	South Kalkie	39	1 x 4 in.	4 ver.	30	7	10	17,000
W. T. Hopkins	South Kalkie	34	2 x 6 in. 1 x 5 in.	7 ver.	34	2	27	55,000
G. Marano	South Kalkie	58	4 x 4 in.	6 ver.	30	10	37	45,000
S. Marano	South Kalkie	42	3 x 3 in.	5 ver.	43	..	22	30,000
V. Parisi	South Kalkie	35	1 x 4 in.	4 hor.	38	3	8	14,000
P. Plath	South Kalkie	25	2 x 4 in.	5 hor.	38	1	15	25,000
Stitt and Sons	Sharon	60	2 x 6 in.	4 hor.	43	..	15	17,000
C. E. Tesch	South Kalkie	61	2 x 5 in. 1 x 3 in.	6 hor.	53	2	25	28,000
Thiele Bros.	Alloway	60	2 x 6 in.	7 ver.	60	4	42	50,000
J. T. Thiele	South Kalkie	35	1 x 4 in. 2 x 3 in.	4 hor.	37	2	16	20,000
G. Torrisi	Kepnock	70	2 x 4 in.	5 hor.	50	2	25	30,000
W. Truscott (1)	South Kalkie	40	1 x 4 in. 1 x 3 in.	4 hor.	40	1	12	20,000
W. Truscott (2)	South Kalkie	42	1 x 5 in. 1 x 3 in.	5 hor.	42	2	13	27,000
F. J. Walk	South Kalkie	36	2 x 5 in.	5 ver.	36	2	17	30,000
A. Zielke	Kepnock	55	2 x 4 in.	$\frac{5}{6}$ hor.	45	..	30	30,000

*NOTE.—This is not a complete list of Bundaberg irrigation plants, but is a cross section taken to illustrate the local conditions.

became still higher with the 20-inch artificial watering. This figure was not reduced by rain. The effect of the potash content of the water in increasing the exchangeable potassium in the soil is noticeable.

These results indicate that the water, far from being of poor quality, as its total solids and total chloride content would suggest, is of good quality for irrigation purposes. This fact is reflected by the Figure of Merit for the water, which is 1·11.

The miscellaneous waters of which the partial analyses are shown in Table 7 are all from areas which are not influenced by tidal streams. Depths of the wells or bores vary from 10 feet to 100 feet, and they were put down during the 1945-46 drought in search of water supplies either for irrigation or for stock. These, and many others analysed in recent years. indicate the presence of highly saline springs over a wide area of this district. The sample from Snake Creek was taken when the stream had ceased running, and it was noticed that horses would not drink the water in the series of waterholes. Adulteration by a saline spring is apparent from the analysis. At least two of the four waters containing free acid are from shallow wells in tea-tree swamp areas where considerable depths of organic residues were in existence.

The area in which all of these unsuitable waters were located is a development of marine tuffaceous beds of Cretaceous age which runs in an arcuate band through Childers, Booyal, and Bullyard to Baffle Creek This geological formation appears to be associated with saline springs, in some of which the salt content is abnormally high.

REFERENCES.

BRYAN, W. H., and MASSEY, C. H. 1926. The geological range of the Tiaro Series. Proc. Roy. Soc. Qld. XXXVII.: 108-20.

CASSIDY, N. G. 1944. Natural waters of the Queensland coastal belt. Qld. J. Agric. Sci. 1: 128-39.

DIXEY, F. 1931. A Practical Handbook of Water Supply.

KING, N. J. 1935. Soils of the Bundaberg area. Cane Growers' Quart. Bull. 2: 135-8.

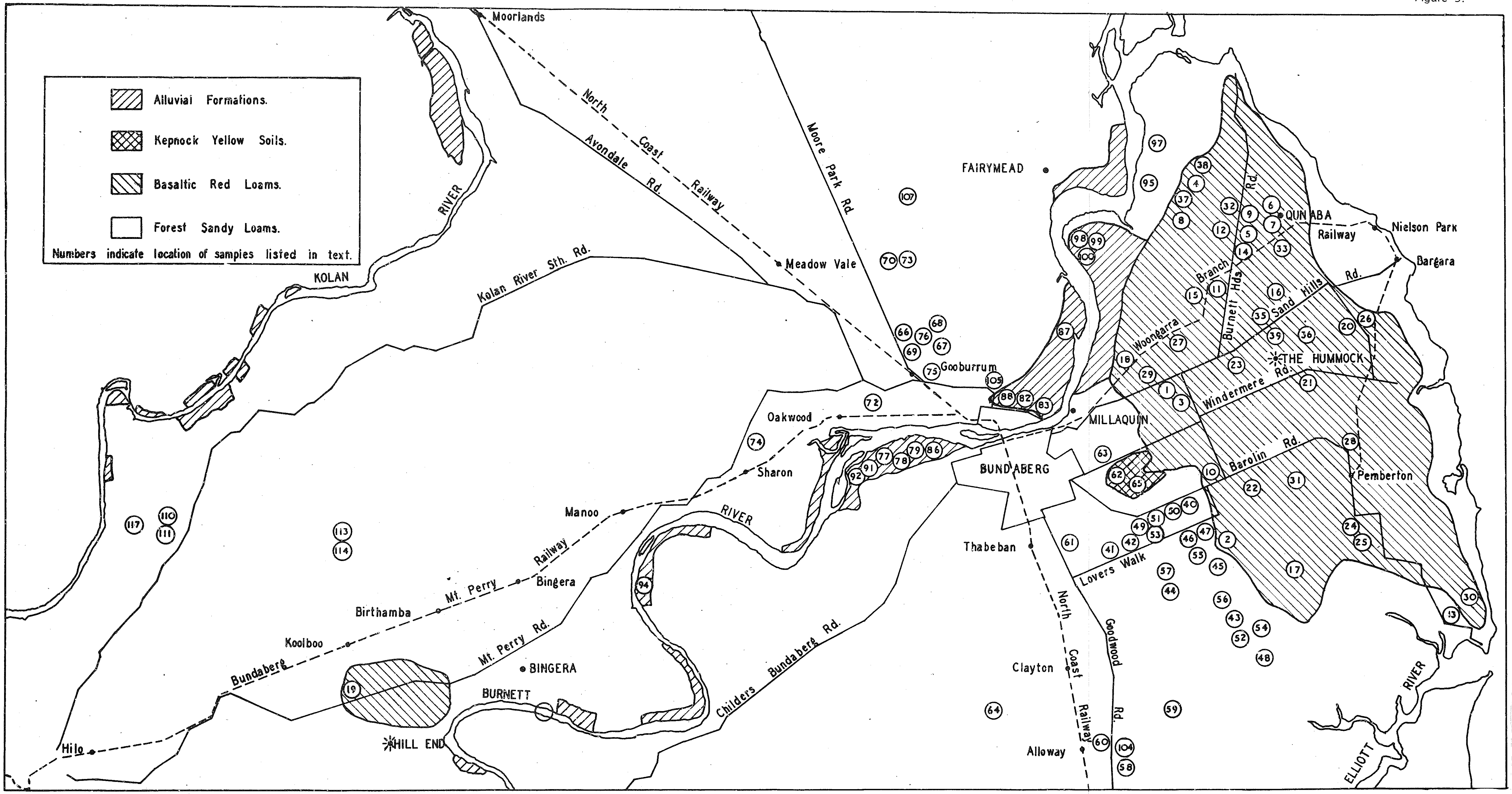
MAXWELL, W. ANN. Rpt. Bur. Sugar Expt. Stn. Qld. 1905-06.

PIPER, C. S. 1942. Soil and Plant Analysis.

SCOTT, W. W., and FURMAN, N. H. 1939. Standard Methods of Chemical Analysis, 5th ed.

MAP OF THE BUNDABERG DISTRICT, SHOWING THE AREAS SAMPLED. NUMBERS REFER TO WATER NUMBERS GIVEN IN THE TABLES.

Figure 3.



LOCATIONS OF WATER SAMPLES
IN THE BUNDABERG IRRIGATION SURVEY