RIVER WATER QUALITY IN THE NORTHERN SUGAR AREAS

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Abstract

Water samples were taken at monthly intervals from the Mkuze, Usutu, Komati, Lomati and Crocodile rivers, for a year or longer, and their chemical composition determined. The suitability of water from each river for irrigation purposes is discussed in the light of soil properties and rainfall. The Usutu, Komati, Lomati and Crocodile rivers have low salinity and sodicity hazards, while the Mkuze river has a moderate salinity and a high sodicity hazard. Analyses of Pongola river water show this to have a moderate sodicity and a fairly low salinity hazard.

Introduction

Successful irrigation agriculture on a permanent basis is dependent on an adequate supply of irrigation water of satisfactory quality, and on sound water management practices. This has been amply demonstrated in the arid zones of many countries of the world where large tracts of land have been abandoned as a result of deterioration of the soil.

The term "satisfactory quality" is difficult to define categorically since crop, climate and soil properties must be taken into account when assessing the suitability of water for irrigation. In the intensively irrigated Lowveld areas of the South African sugar industry climatic conditions are generally similar, but soils vary markedly. Generally the higher the rainfall and the more permeable the soil, the poorer the quality of water that can safely be used for irrigation.

Factors considered in determining water quality for irrigation are:

Salinity hazard
Sodicity hazard
Bicarbonate plus carbonate concentration
Boron content

Although sugarcane could not be produced in the Lowveld regions without irrigation, the rainfall in these areas (roughly 600 mm per annum) is fairly high in comparison with that in arid zones of many other countries. In consequence the leaching effect is high, which reduces the danger of soil salinization with a particular water, provided that soil drainage is not limiting.

Sodicity is the major problem in our salt-affected soils. These are difficult to restore to their original condition because soil structure is often adversely affected and a chemical ameliorant such as gypsum needs to be applied in order to displace sodium from the soil. The sodium salts originate either from irrigation water or from soil, as a product of weathering. Assessment of the sodium hazard of irrigation water is therefore of major importance.

Few data were available regarding the chemical composition of the Mkuze, Usutu, Komati, Lomati and Crocodile rivers. These, together with the Pongola river, constitute the lifeblood of the northern sugar areas. It was therefore decided to undertake a programme of sampling and chemical analysis of these rivers.

Procedure

Water samples were taken at approximately monthly intervals, for at least a year, from one or more selected points along each river (see Table 1) and the following measurement made:

EC (electrical conductivity)	using a Phillips PW9501 conductivity meter.
Na^+, Ca^{++} and Mg^{++} . .	using a Varian Techtron 1 200 atomic absorption spectrophotometer.
pH	a laboratory determination made within 3 days of sampling. Sample bottles filled completely in order to minimise any change in pH due to gas exchange.
$CO_3^=$ and HCO_3^- . . .	by titration with acid (USDA Handbook 60[12]).
Cl^-	by titration with $Ag\ NO_3$ solution using K_2CrO_4 indicator (USDA Handbook 60[12]).
B	colorimetrically using carmine colour complex (USDA Handbook 60[12]).

For the calcium and magnesium determinations it was found necessary to treat all unknowns and standards with a strontium chloride solution (5 000 ppm strontium) to prevent losses due to the formation of calcium and magnesium carbonates in the flame of the atomic absorption spectrophotometer.

At the time of sampling a visual assessment of river flow was made and described as very low, low, moderate, high or very high.

Results and discussion

Detailed chemical analyses of all river water samples are given in Appendix I, while averaged chemical data for each river are shown in Table 1. Individual EC levels for each sampling date are shown graphically in Figs. 1-4. Pongola river water analyses, obtained from a Natal Town and Regional Planning Report,[9] are included in Table 1 for comparison.

It was anticipated that high flow rates would be associated with low EC levels in all rivers, and vice versa. This generally applied to the Mkuze and Usutu rivers (see Appendix 1), but it is peculiar that, in the Komati, Lomati and Crocodile rivers, comparatively high flow rates were sometimes associated with relatively high EC levels, though the absolute variation in salt level was rather small.

Salinity hazard

The Usutu, Komati, Lomati and Crocodile river waters are chemically very pure and are rated as having a low salinity hazard. However, the Crocodile river at Tenbosch has a slightly higher salinity level than that in the canal, due to drainage water it receives during its passage through the sugar areas.

Although the water at Tenbosch has a moderate salinity hazard rating, under the local climatic conditions this is considered to be low. Pongola river water is also rated as having a moderate salinity hazard but irrigation with it is unlikely to cause salinity problems unless soil drainage is limiting.

Mkuze river water has, on average, a very high salinity hazard by USDA standards (USDA Handbook 60[12]). Fig. 1 shows the great fluctuation in salt level that occurs in this river, the maximum annual EC level often being ten times

TABLE 1

Average chemical composition of river water samples

River + Site	No. of samples meaned	EC (mmhos/cm) at 25°C	pH	Ionic concentrations Na meq/l	Ca meq/l	Mg meq/l	HCO_3 meq/l	Cl meq/l	B† ppm	pH_c*	SAR_{iw}	USDA quality rating	SAR_{dw} LF = 0,2	SAR_{dw} LF = 0,05
Mkuze (at bridge on old main road)	26	1,914	7,8	10,30	3,58	6,08	4,50	12,47	0,02 0,19	7,02	4,12	C_3S_1	22,0	44,0
Pongola‡ (Pongola settlement area)	4	0,627	8,2	3,97	1,07	1,30	4,72	1,97	—	7,95	3,64	C_2S_1	11,8	23,6
Usutu (Big Bend Canal)	27	0,096	7,3	0,39	0,29	0,28	0,76	0,16	< 0,01	8,80	0,74	C_1S_1	1,0	2,0
Komati (Swaziland Irrigation Scheme Canal)	21	0,113	7,6	0,33	0,37	0,50	0,97	0,13	< 0,01	8,53	0,50	C_1S_1	1,0	2,0
Komati (Komatidraai)	14	0,162	7,6	0,57	0,46	0,63	1,28	0,28	—	8,28	0,77	C_1S_1	1,9	3,8
Lomati (Hectorspruit)	14	0,186	7,4	0,52	0,67	0,68	1,33	0,28	—	8,21	0,64	C_1S_1	1,7	3,4
Crocodile (Tenbosch)	24	0,291	7,7	0,93	0,81	1,21	2,30	0,39	0,03	7,80	0,91	C_2S_1	3,3	6,6
Crocodile (Crocodile Canal)	24	0,130	7,9	0,26	0,49	0,58	1,08	0,14	—	8,37	0,35	C_1S_1	0,8	1,6

† For Mkuze river two measurements are given for high and low flow respectively.
For other rivers the figure represents the mean of two similar levels.
‡ Data obtained from Natal Town and Regional Planning Report.[9]

higher than the minimum. There is consistently a period of low flow during spring and early summer for each year sampled, and the salt load at these times is very high, quite commonly reaching levels in excess of 4 mmhos/cm (or 26 tons of salt per hectare metre). It is considered that water with an EC of 3 mmhos/cm or more is likely to do more harm than good to the crop. Such a solution exerts an osmotic pressure of −1,0 bar which significantly inhibits water uptake. With sprinkler irrigation such a high salt level is likely to cause leaf burn to sugarcane. Between December and June the water quality is generally quite satisfactory for irrigation and it is sound practice to store water during these months for irrigation later on.

A recent soil salinity survey in the Mkuze area indicated that the accumulation of salts in the soil was rather less than had been expected. A conservative estimate of the amount of salt added to the soil during 15 years of irrigation with Mkuze river water totalled the equivalent of an EC of 8 mmhos/cm in the upper two metres of soil, assuming that no drainage had occurred. Samples taken from Arcadia series soils (black cracking clays with poor internal drainage) indicated that only 10% of the area (which has no artificial drains) has EC levels in excess of 4 mmhos/cm. The other soil series occurring in the survey area (Shortlands, red structured clays, and Shorrocks, red porous loams) have far better internal drainage properties, and no EC levels in excess of 2 mmhos/cm were encountered.

Sodicity hazard

This is assessed according to the sodium adsorption ratio (SAR) which is defined as

$$\frac{(Na)}{\sqrt{\frac{(Ca) + (Mg)}{2}}}$$

where ionic concentrations are in milliequivalents per litre.

Irrigation with water of high SAR will tend to induce a high exchangeable sodium level in the soil and may consequently result in poor soil permeability due to swelling and/or dispersion of clay particles (McNeal and Coleman[8]).

In assessing the sodium hazard of irrigation water is it necessary to take bicarbonate (and carbonate) content into account. If calcium (and magnesium) plus bicarbonate ions are added to the soil by irrigation the following reaction tends to occur.

$$Ca^{++} + 2\,HCO_3^{-} \longrightarrow Ca\,CO_3 \downarrow + H_2O + CO_2 \uparrow$$

Removal of calcium (or magnesium) from the soil solution effectively increases its SAR and consequently the exchangeable sodium level of the soil.

The bicarbonate hazard is measured by the pH_c* value which is the calculated pH of the water when it is in chemical equilibrium with calcium and magnesium carbonate (Bower, Ogata and Tucker[3]). The lower the pH_c* value the greater is the tendency for carbonate precipitation. Levels of $CO_3 + HCO_3$ and Ca + Mg strongly influence pH_c*, high levels of each tending to reduce the value. The total electrolyte concentration has a minor influence but a high level tends to increase pH_c*.

It has been shown in lysimeter experiments that the pH_c* value of irrigation water is a useful index of the amount of carbonate that will precipitate in a soil irrigated with the particular water (Bower, Ogata and Tucker[3]; Bower and Wilcox[1]; Bower, Wilcox, Akin and Keyes[2]).

Langelier[7] proposed an index, termed the *saturation index*, for indicating the extent to which waters flowing through metal pipes will precipitate or dissolve calcium carbonate.

Saturation index = actual pH of water − pH_c.

A positive index shows a tendency for calcium carbonate precipitation and a negative one a tendency for calcium carbonate dissolution. For soils this has been modified and the pH of the soil substituted for the pH of the water. This is justified by the fact that soils are highly buffered and water applied to the soil will assume a very similar pH. Further, the pH of a calcareous soil (8,4) is proposed for general use since carbonate precipitation will eventually raise soil pH to this level.

The pH_c value has also been modified to allow for magnesium carbonate as well as calcium carbonate precipitation and is called pH_c^* (Bower, Ogata and Tucker[3]). Thus $8{,}4 - pH_c^*$ is analagous to Langelier's saturation index.

Prediction of steady state SAR of drainage water

Attempts have been made by various workers (Bower *et al*[3]; Rhoades[10]) to predict sodium build up in soil on a basis of the composition of the irrigation water. The semi-empirical

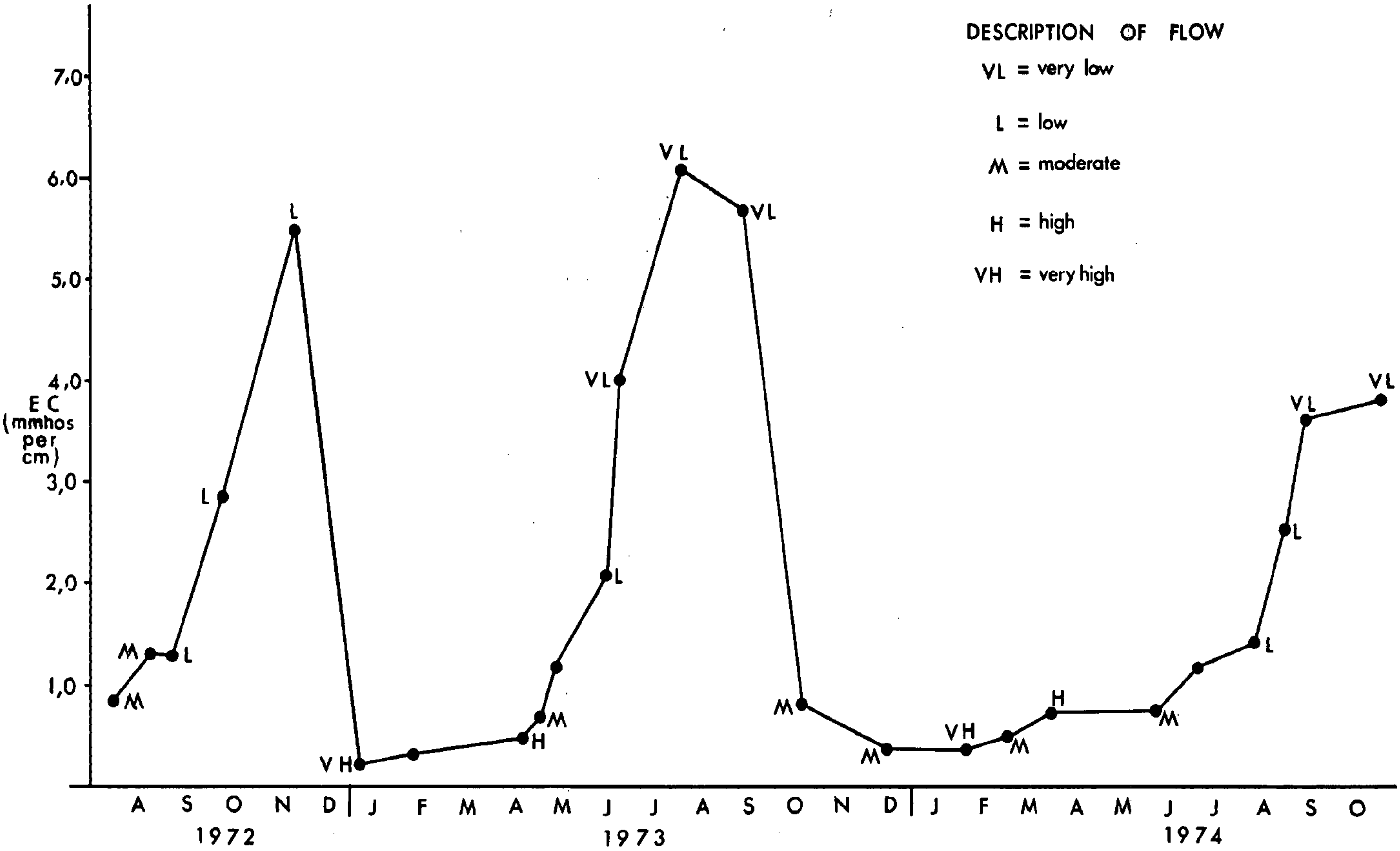

FIGURE 1 Fluctuation in EC level with varying flow of the Mkuze River.

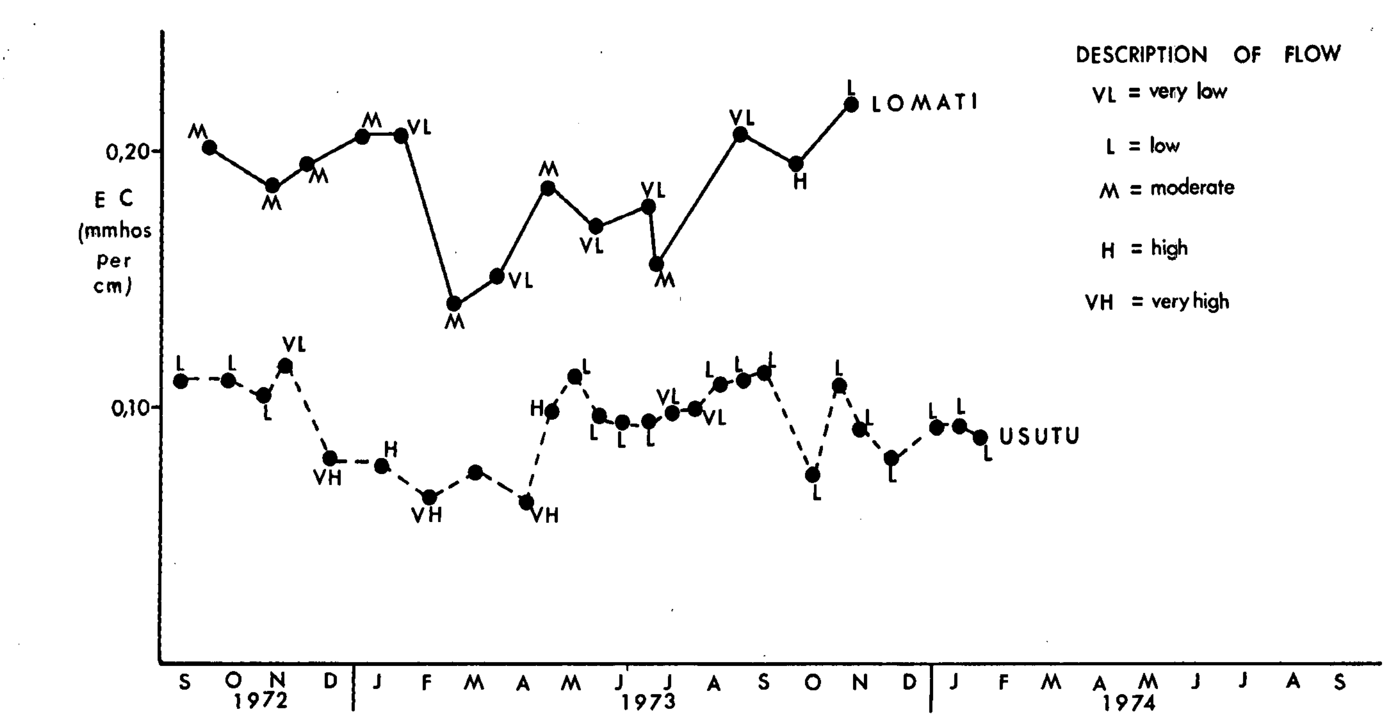

FIGURE 2 Fluctuation in EC level with varying flow of the Usutu and Lomati rivers.

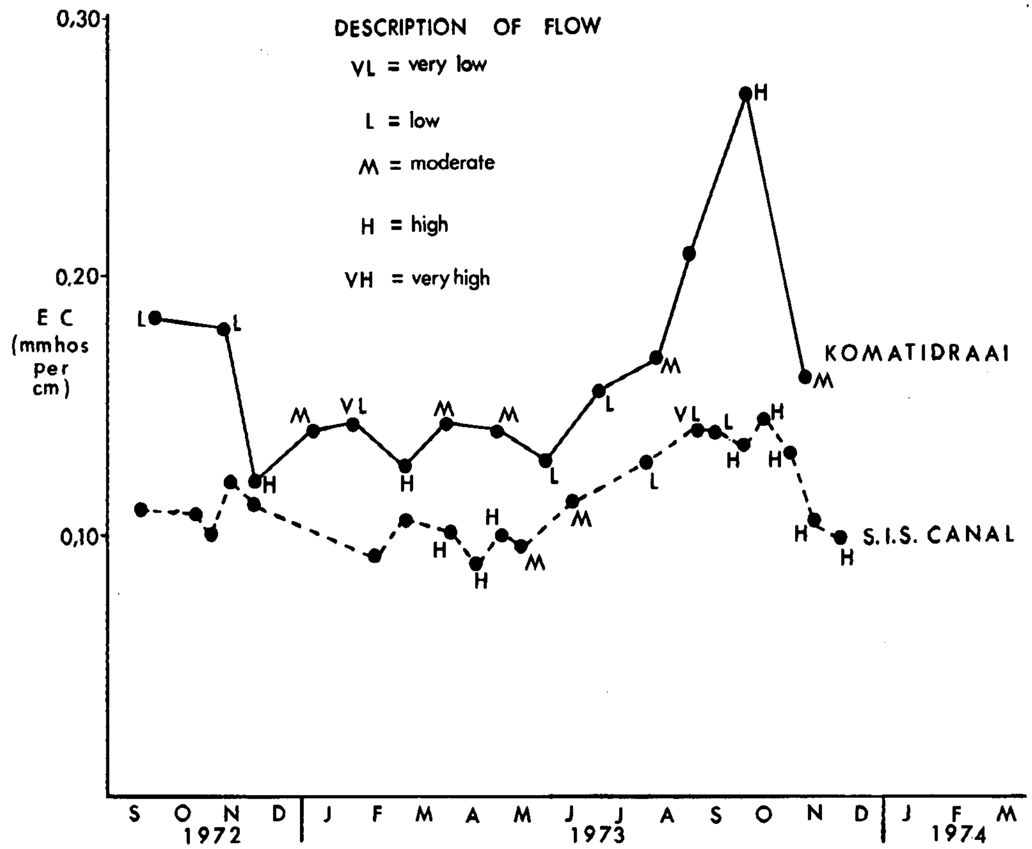

FIGURE 3 Fluctuation in EC level with varying flow of the Komati River.

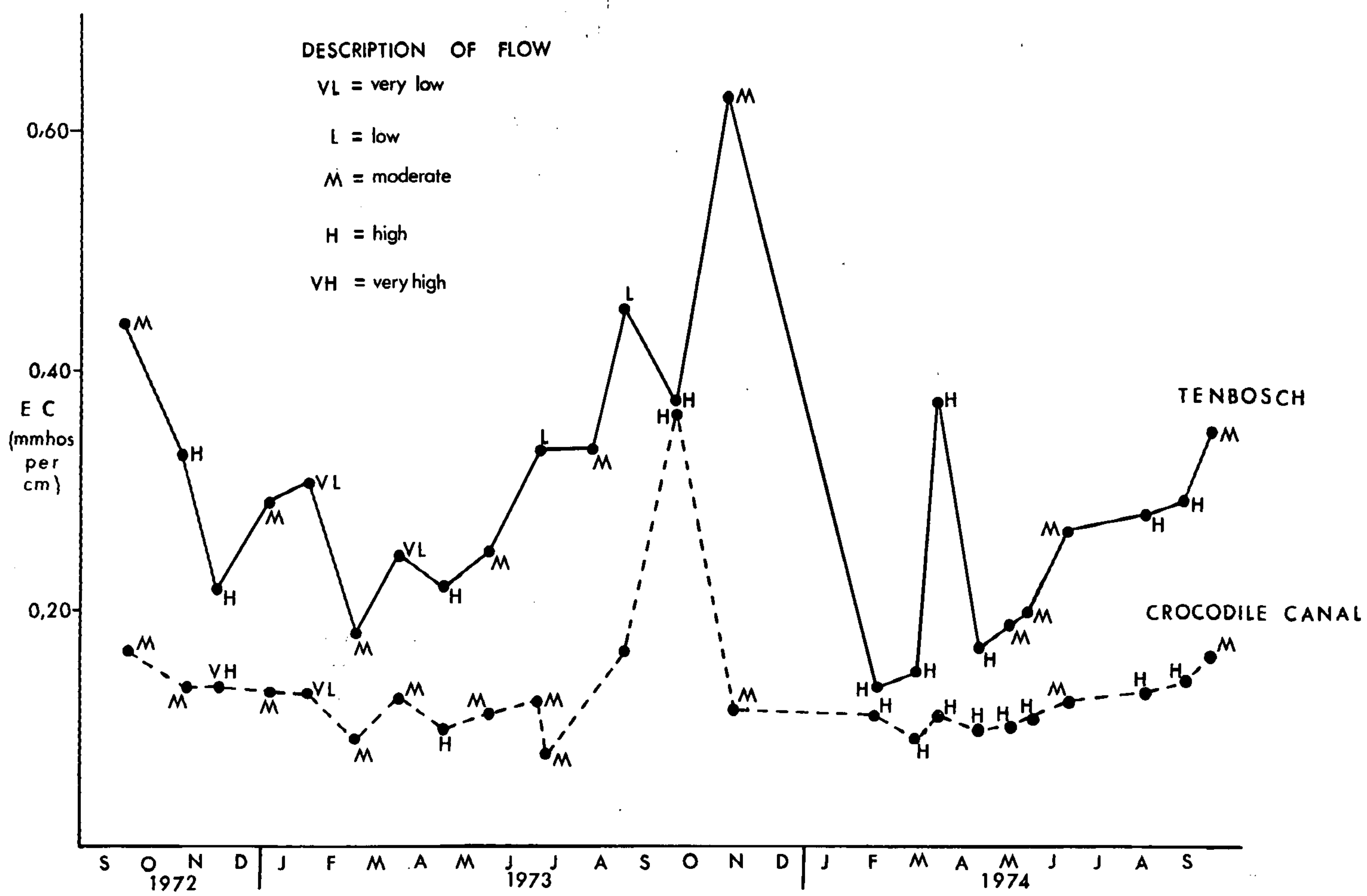

FIGURE 4 Fluctuation in EC level with varying flow of the Crocodile River.

equation has undergone a number of refinements, the most advanced form being proposed by Rhoades[10] viz:

$$SAR_{dw} = \frac{y^{(1 + 2LF)}}{\sqrt{LF}} SAR_{iw} [1 + (8,4 - pH_c^*)]$$

where SAR_{dw} and SAR_{iw} = SAR of water draining from the root zone and of irrigation water respectively.

LF = leaching fraction, i.e. fraction of total amount of water accepted by the soil that drains from the root zone.

$y^{(1 + 2LF)}$ = mineral weathering factor to allow for Ca and Mg contributions to the soil solution.

Information on mineral weathering in the soil is lacking at present and the weathering factor has been omitted in the SAR_{dw} predictions in Table 1. Since our soils generally contain very small amounts of primary weatherable minerals, the omission of this factor is unlikely to influence this prediction markedly.

The normal degree of leaching that occurs is likely to fall into the leaching fraction range of 0,2 to 0,05 for the different soil types and therefore these values are used in Table 1.

Although this equation has been developed and shown to yield a sound prediction of SAR_{dw} under the controlled conditions of a lysimeter experiment, it is felt that it is also useful as a guide under field conditions. It should be pointed out that analytical figures in Table 1 are averaged over both winter and summer periods, whereas more irrigation water is applied in summer when water quality is most favourable. Hence the actual quality of irrigation water will, on average, be slightly better than that indicated in the table.

The Usutu, Komati, Lomati and Crocodile rivers have low sodicity hazards, provided that water tables are not allowed to build up in the soil.

In the light of information on the effect of high SAR levels of the soil solution on soil permeability (Hensley[4]; Johnston[6]) the Mkuze, and to a lesser extent the Pongola rivers, present a hazard to the hydraulic conductivity of Arcadia, Bonheim, Estcourt and Shortlands series soils and to those of related series. The hydraulic conductivity of the Shorrocks series and related soils is unlikely to be affected.

Soil crusting

During investigations into soil crusting on the Makatini flats, Hutson[5] found that a high exchangeable sodium level at the soil surface was the primary cause of high crust strength. Samples taken from a Shorrocks series soil showed ESP (exchangeable sodium percentage) levels of 21,0, 14,0 and 9,4 in the 0-2,5, 2,5-5,0 and 5,0-10,0 cm depths respectively. This soil, a red, weakly structured sandy loam, is particularly susceptible to crust formation by virtue of its particle size distribution, weak structure and clay mineral composition.

At the soil surface high temperatures and marked concentration of the soil solution due to evaporation enhance carbonate precipitation. This causes the SAR of the soil solution to increase, which in turn raises the ESP.

Crusting has been observed on Shorrocks series soils irrigated with Mkuze river water and, although no analyses are available, ESP levels within the crust are expected to be high.

Boron hazard

Measured levels of this potentially toxic element (see Table 1) are well below the toxic limit of 0,33 ppm for boron sensitive crops (USDA Handbook 60[12]).

Conclusions

Soil drainage is vital to salinity control. Any irrigation water, no matter how pure chemically, is capable of creating soil salinity problems if water tables are allowed to develop in the soil. The installation of artificial drains, where necessary, should be regarded as a prerequisite for successful irrigation agriculture.

The Mkuze is the only river that is considered to present a significant salinity hazard, but soil samples from irrigated fields indicate that the leaching effect of rainfall is generally effective in maintaining a favourable salt balance. The Usutu, Komati, Lomati and Crocodile rivers have very low salinity hazards. The Pongola river has a somewhat higher salinity hazard but under reasonable conditions of soil drainage, salinity problems are unlikely to occur.

The sodicity hazard of the Usutu, Komati and Crocodile rivers is generally very low, However, the high chemical purity of these waters could adversely affect the hydraulic conductivity of soils that are already sodic, by diluting the soil solution to an excessive degree (Rose[11]).

The Pongola river is considered to present a hazard in the long term to the hydraulic conductivity of the Arcadia, Bonheim, Estcourt and possibly Shortlands series soils, while the Mkuze river presents a more serious hazard to all of these soil series. Neither river is likely to affect the hydraulic conductivity of soils of the Shorrocks series adversely. The sodicity hazard of these two rivers is largely induced by potential precipitation of calcium and magnesium carbonates.

Boron concentrations in all rivers considered were found to present no danger to sugarcane growth.

As agriculture and industry develop in the catchment areas of all these rivers, the quality of the water will gradually deteriorate. The analytical data reported in this paper should provide an adequate basis for comparison with future analyses.

Acknowledgements

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APPENDIX I

Chemical composition of all river water samples

River + Sampling point	Date of sampling	pH	EC at 25°C (mmhos/cm)	Ionic concentrations (meq/l) Na+	Ca++	Mg++	HCO_3^-	Cl−	SAR	pHc*	Flow
Mkuze River (at bridge on Mkuze-Gollel Road)	28.7.72	7,95	0,832	4,12	1,90	2,55	3,20	3,69	2,76	7,40	Moderate
	21.8.72	7,70	1,278	6,52	1,95	4,11	4,10	6,70	3,75	7,19	Moderate to low
	5.9.72	8,04	1,294	6,52	1,90	3,45	4,10	6,52	3,99	7,24	Low
	6.10.72	8,00	2,851	15,47	1,10	8,72	6,30	20,78	6,98	6,89	Low
	23.11.72	7,65	5,485	29,50	4,10	19,74	8,26	49,10	8,54	6,49	Low
	4.1.73	7,75	0,240	1,56	0,13	0,62	1,57	0,61	2,55	8,39	Very high
	9.2.73	7,32	0,341	1,35	0,51	0,95	2,00	0,19	1,58	8,01	—
	19.4.73	7,86	0,479	1,59	1,15	1,48	1,00	0,69	1,39	8,08	High
	2.5.73	7,23	0,698	3,17	2,45	2,02	1,60	2,71	2,12	7,69	Moderate to high
	11.5.73	8,18	1,159	5,26	3,00	3,45	2,62	0,56	2,93	7,36	Moderate
	17.5.73	7,70	1,234	5,87	3,30	4,03	3,36	5,19	3,07	7,21	Low
	13.6.73	8,10	2,057	10,00	4,05	6,50	5,86	13,15	4,35	6,85	Low
	21.6.73	7,80	4,009	21,52	9,00	13,57	7,56	29,28	6,41	6,51	Very low
	1.8.73	7,85	6,070	36,96	13,00	21,38	9,60	50,82	8,91	6,30	Very low
	11.9.73	7,85	5,737	28,70	11,50	18,10	7,72	44,49	7,46	6,43	Very low
	19.10.73	7,30	0,810	3,28	2,05	2,20	2,10	3,25	2,25	7,60	Moderate
	13.12.73	8,00	0,382	1,48	1,13	1,14	1,74	1,14	1,39	7,89	Moderate
	5.2.74	7,42	0,350	1,36	0,98	0,99	1,18	1,13	1,37	8,12	Very high
	1.3.74	7,83	0,498	1,89	1,77	1,52	1,37	1,23	1,47	7,86	Moderate
	31.3.74	7,70	0,718	2,96	1,60	1,97	2,40	3,03	2,21	7,60	High
	6.6.74	7,75	0,725	3,69	1,80	2,30	2,79	3,00	2,58	7,48	Moderate
	3.7.74	7,80	1,153	5,83	2,65	3,42	3,81	5,56	3,34	7,27	—
	8.8.74	8,00	1,369	7,39	3,65	4,52	4,37	7,07	3,68	7,06	Low
	28.8.74	8,00	2,547	16,52	5,00	6,83	7,16	14,03	6,79	6,81	Low
	12.9.74	7,80	3,633	21,43	7,45	11,76	6,94	26,99	6,92	6,64	Very low
	1.11.74	7,60	3,811	23,91	6,00	10,69	14,32	22,60	8,28	6,37	Very low
Usutu River (Big Bend Canal)	11.9.72	7,41	0,112	0,44	0,32	0,34	0,92	0,18	0,77	8,65	Low
	9.10.72	7,99	0,112	0,42	0,39	0,34	0,86	0,19	0,70	8,65	Low
	3.11.72	7,80	0,104	0,38	0,38	0,34	0,95	0,19	0,63	8,60	Low
	15.11.72	5,60	0,118	0,41	0,31	0,30	1,02	0,18	0,74	8,63	Very low
	14.12.72	6,95	0,080	0,27	0,31	0,27	0,78	0,10	0,50	8,78	Very high
	15.1.73	7,30	0,079	0,26	0,25	0,26	0,80	0,10	0,51	8,81	High
	15.2.73	7,48	0,065	0,30	0,20	0,19	0,58	0,02	0,68	9,06	Very high
	15.3.73	7,50	0,075	0,33	0,24	0,23	0,60	0,13	0,68	8,98	—
	16.4.73	7,30	0,064	0,26	0,21	0,19	0,64	0,10	0,58	9,02	Very high
	1.5.73	7,45	0,099	0,39	0,24	0,24	0,70	0,11	0,80	8,91	High
	16.5.73	7,75	0,113	0,47	0,28	0,28	0,80	0,13	0,89	8,78	Low to moderate
	1.6.73	7,40	0,096	0,42	0,27	0,27	0,83	0,14	0,81	8,78	Low
	15.6.73	7,58	0,093	0,39	0,27	0,26	0,82	0,14	0,76	8,78	Low
	1.7.73	7,19	0,093	0,43	0,29	0,27	0,73	0,19	0,81	8,81	Low
	16.7.73	6,90	0,099	0,45	0,27	0,26	0,77	0,20	0,87	8,81	Very low
	1.8.73	7,75	0,100	0,46	0,29	0,30	0,83	0,20	0,85	8,75	Very low
	15.8.73	7,70	0,109	0,42	0,31	0,30	0,72	0,25	0,76	8,78	Low
	1.9.73	7,70	0,112	0,49	0,31	0,30	0,74	0,19	0,89	8,77	Low
	15.9.73	8,00	0,115	0,55	0,31	0,33	0,75	0,23	0,97	8,75	Low
	15.10.73	7,20	0,073	0,30	0,26	0,24	0,50	0,19	0,60	9,02	Low
	1.11.73	7,10	0,110	0,45	0,35	0,35	0,74	0,15	0,78	8,74	Low
	15.11.73	7,32	0,092	0,42	0,32	0,27	0,80	0,15	0,77	8,76	Low
	1.12.73	6,85	0,079	0,31	0,24	0,19	0,54	0,14	0,67	9,03	Low
	1.1.74	6,75	0,093	0,45	0,35	0,35	0,71	0,21	0,76	8,75	Low
	15.1.74	5,65	0,093	0,37	0,28	0,30	0,72	0,15	0,68	8,82	Low
	1.2.74	6,95	0,088	0,36	0,25	0,25	0,74	0,15	0,72	8,86	Low
	12.9.74	7,40	0,122	0,45	0,30	0,38	0,91	0,26	0,78	8,63	Low

APPENDIX I — *continued*

River + Sampling point	Date of sampling	pH	EC at 25°C (mmhos/cm)	Ionic concentrations (meq/l)					SAR	pHc*	Flow
				Na^+	Ca^{++}	Mg^{++}	HCO_3^-	Cl^-			
Komati River (Swaziland Irrigation Scheme Canal)	19.9.72	7,82	0,110	0,39	0,51	0,57	1,01	0,17	0,53	8,40	—
	23.10.72	8,10	0,108	0,35	0,39	0,53	1,05	0,13	0,52	8,44	—
	1.11.72	7,45	0,100	0,26	0,34	0,44	0,96	0,12	0,42	8,56	—
	15.11.72	7,40	0,120	0,32	0,37	0,49	0,94	0,20	0,49	8,53	—
	30.11.72	7,68	0,111	0,31	0,36	0,48	1,04	0,13	0,48	8,49	—
	15.2.73	7,20	0,091	0,32	0,31	0,40	0,84	0,14	0,54	8,66	—
	1.3.73	7,40	0,106	0,34	0,34	0,41	1,20	0,10	0,56	8,48	—
	1.4.73	7,70	0,100	0,30	0,32	0,44	0,90	0,11	0,49	8,60	High
	16.4.73	7,75	0,088	0,26	0,30	0,41	0,80	0,07	0,44	8,68	High
	1.5.73	7,70	0,100	0,26	0,33	0,52	0,90	0,06	0,40	8,56	High
	15.5.73	7,55	0,095	0,26	0,31	0,49	0,82	0,16	0,41	8,62	Moderate
	Uncertain	7,05	0,101	0,30	0,31	0,44	0,93	0,07	0,49	8,59	Low
	15.6.73	7,40	0,112	0,30	0,32	0,49	1,01	0,11	0,47	8,51	Moderate
	1.8.73	7,90	0,128	0,31	0,42	0,54	1,03	0,11	0,45	8,44	Low
	1.9.73	8,42	0,141	0,37	0,45	0,63	1,14	0,13	0,50	8,35	Very low
	15.9.73	8,24	0,140	0,36	0,44	0,63	1,14	0,10	0,49	8,36	Low
	1.10.73	7,02	0,133	0,35	0,42	0,60	0,97	0,21	0,49	8,46	High
	15.10.73	7,30	0,145	0,41	0,45	0,60	1,03	0,24	0,57	8,40	High
	1.11.73	7,42	0,130	0,46	0,43	0,48	0,98	0,17	0,68	8,50	High
	15.11.73	7,40	0,104	0,32	0,36	0,44	0,87	0,09	0,50	8,58	High
	1.12.73	7,35	0,099	0,33	0,32	0,39	0,87	0,05	0,55	8,63	High
Komati River (Komatidraai)	29.9.72	7,55	0,184	0,70	0,46	0,72	1,40	0,35	0,91	8,23	Low to moderate
	7.11.72	8,10	0,180	0,67	0,48	0,72	1,45	0,42	0,87	8,21	Low
	30.11.72	7,20	0,120	0,43	0,36	0,44	0,95	0,16	0,68	8,56	High
	4.1.73	7,10	0,140	0,52	0,42	0,58	1,24	0,19	0,74	8,35	Moderate
	31.1.73	7,68	0,143	0,53	0,43	0,60	1,36	0,17	0,74	8,30	Very low
	1.3.73	7,28	0,125	0,48	0,34	0,46	0,96	0,13	0,76	8,55	High
	30.3.73	7,48	0,143	0,54	0,41	0,54	1,20	0,19	0,78	8,39	Moderate
	30.4.73	6,64	0,140	0,49	0,43	0,53	1,19	0,16	0,71	8,40	Moderate
	31.5.73	7,75	0,128	0,43	0,38	0,58	1,08	0,23	0,62	8,43	Low to moderate
	3.7.73	7,78	0,155	0,52	0,39	0,65	1,29	0,28	0,72	8,31	Low to moderate
	9.8.73	7,88	0,167	0,59	0,47	0,67	1,29	0,36	0,78	8,26	Moderate
	31.8.73	7,90	0,207	0,67	0,49	0,79	1,46	0,37	0,84	8,18	—
	5.10.73	7,62	0,269	1,04	0,67	0,98	1,81	0,73	1,15	7,99	High
	9.11.73	8,10	0,161	0,42	0,72	0,51	1,23	0,22	0,54	8,29	Moderate
Lomati River (Hectorspruit)	29.9.72	7,25	0,202	0,65	0,69	0,72	1,41	0,39	0,77	8,14	Moderate to high
	7.11.72	7,80	0,186	0,61	0,67	0,67	1,39	0,36	0,75	8,19	Moderate
	30.11.72	7,30	0,197	0,58	0,70	0,70	1,41	0,37	0,69	8,15	Moderate
	4.1.73	7,20	0,207	0,56	0,73	0,66	1,40	0,21	0,69	8,17	Moderate
	31.1.73	7,60	0,207	0,58	0,60	0,63	1,40	0,08	0,74	8,21	Low to very low
	1.3.73	7,10	0,140	0,47	0,44	0,52	1,06	0,08	0,68	8,44	Moderate
	30.3.73	7,40	0,151	0,50	0,48	0,54	1,18	0,20	0,70	8,35	Very low
	30.4.73	6,30	0,187	0,59	0,73	0,69	1,26	0,31	0,70	8,19	Moderate
	31.5.73	7,40	0,170	0,51	0,58	0,67	1,24	0,29	0,65	8,25	Very low
	3.7.73	7,50	0,179	0,50	0,73	0,67	1,39	0,23	0,60	8,17	Very low
	7.7.73	7,82	0,156	0,32	0,64	0,63	1,12	0,28	0,40	8,28	Moderate
	31.8.73	8,10	0,207	0,38	0,85	0,84	1,54	0,34	0,41	8,03	Very low
	5.10.73	7,30	0,195	0,54	0,73	0,76	1,21	0,46	0,63	8,19	High
	9.11.73	7,70	0,218	0,47	0,85	0,79	1,61	0,38	0,52	8,02	Low

APPENDIX I — *continued*

River + Sampling point	Date of sampling	pH	EC at 25°C (mmhos/cm)	Ionic concentrations (meq/l) Na^+	Ca^{++}	Mg^{++}	HCO_3^-	Cl^-	SAR	pHc*	Flow
Crocodile River (Tenbosch)	29.9.72	8,05	0,437	1,46	1,06	1,72	3,30	0,27	1,24	7,53	Moderate to high
	7.11.72	8,40	0,330	0,98	0,87	1,36	2,51	0,35	0,93	7,72	High
	30.11.72	7,40	0,218	0,61	0,59	0,81	1,44	0,21	0,73	8,15	High
	4.1.73	7,40	0,290	0,74	1,09	1,07	1,93	0,27	0,71	7,86	Moderate
	31.1.73	7,88	0,307	1,03	0,82	1,27	2,82	0,24	1,01	7,71	Very low
	1.3.73	7,47	0,180	0,58	0,57	0,78	1,44	0,12	0,71	8,17	Moderate
	30.3.73	7,98	0,247	0,81	0,64	1,11	2,22	0,27	0,87	7,87	Very low
	30.4.73	7,00	0,219	0,67	0,61	0,89	2,00	0,22	0,77	7,99	High
	31.5.73	7,90	0,248	0,80	0,63	1,06	1,97	0,29	0,87	7,94	Moderate
	3.7.73	7,90	0,333	1,13	0,95	1,40	2,77	0,47	1,04	7,67	Low to moderate
	9.8.73	7,80	0,334	1,09	0,89	1,55	2,80	0,43	0,99	7,64	Moderate
	31.8.73	8,10	0,451	1,52	1,14	1,82	3,51	0,81	1,25	7,49	Low
	5.10.73	7,45	0,372	1,26	1,26	1,37	2,64	0,60	1,10	7,65	High to very high
	9.11.73	7,80	0,627	1,70	1,66	2,32	5,19	0,95	1,20	7,73	Moderate
	18.2.74	7,51	0,133	0,37	0,41	0,54	1,03	0,18	0,53	8,47	High
	14.3.74	7,70	0,147	0,43	0,50	0,67	1,31	0,16	0,57	8,23	High
	28.3.74	7,48	0,374	1,43	0,95	1,23	1,80	1,10	1,37	7,91	High
	25.4.74	6,78	0,166	0,51	0,50	0,76	1,49	0,23	0,65	8,20	High
	16.5.74	7,50	0,185	0,60	0,50	0,85	1,60	0,25	0,72	8,11	Moderate to high
	29.5.74	7,75	0,197	0,60	0,45	0,91	1,66	0,25	0,73	8,08	Moderate to high
	24.6.74	7,75	0,266	0,93	0,65	1,19	2,28	0,24	0,96	7,85	Moderate
	16.8.74	7,90	0,279	0,91	0,84	1,32	2,45	0,38	0,88	7,76	High
	11.9.74	7,90	0,289	0,91	0,90	1,37	2,43	0,43	0,86	7,75	High
	30.9.74	8,55	0,348	1,27	0,97	1,57	2,61	0,63	1,13	7,65	Moderate
Crocodile River (Crocodile Canal)	30.9.72	7,45	0,165	0,39	0,57	0,69	1,30	0,27	0,49	8,22	Moderate to high
	8.11.72	8,50	0,134	0,30	0,50	0,60	1,05	0,17	0,40	8,34	Moderate
	1.12.72	7,60	0,135	0,33	0,51	0,62	1,03	0,16	0,44	8,32	Very high
	4.1.73	7,80	0,130	0,27	0,51	0,63	1,08	0,06	0,36	8,33	Moderate
	31.1.73	7,75	0,129	0,29	0,50	0,59	1,10	0,03	0,39	8,35	Very low
	1.3.73	7,21	0,090	0,23	0,36	0,39	0,96	0,01	0,38	8,56	Moderate
	30.3.73	7,58	0,125	0,24	0,47	0,57	1,20	0,06	0,33	8,33	Moderate
	30.4.73	6,80	0,098	0,24	0,39	0,42	0,81	0,17	0,38	8,61	High
	31.5.73	7,70	0,111	0,23	0,44	0,53	0,98	0,10	0,33	8,46	Moderate to high
	4.7.73	7,77	0,123	0,24	0,44	0,58	1,10	0,12	0,34	8,37	Moderate
	7.7.73	9,70	0,077	0,21	0,34	0,24	0,15†	0,10	0,39	8,98	Moderate
	31.8.73	8,10	0,163	0,26	0,62	0,70	1,25	0,15	0,32	8,22	—
	5.10.73	7,53	0,357	0,70	1,19	1,60	1,81	0,89	0,59	7,77	High to very high
	12.11.73	7,70	0,116	0,24	0,46	0,48	0,96	0,08	0,35	8,51	Moderate to high
	18.2.74	8,68	0,110	0,18	0,53	0,40	0,86	0,10	0,27	8,54	High
	14.3.74	8,21	0,091	0,17	0,33	0,41	0,82	0,05	0,28	8,65	High
	28.3.74	7,62	0,111	0,30	0,45	0,58	0,92	0,08	0,42	8,47	High
	25.4.74	8,02	0,097	0,19	0,35	0,48	0,90	0,03	0,29	8,56	High
	16.5.74	8,20	0,102	0,19	0,35	0,49	0,88	0,09	0,29	8,57	High
	29.5.74	7,68	0,108	0,20	0,35	0,52	0,96	0,09	0,30	8,52	High
	24.6.74	7,55	0,123	0,21	0,40	0,58	1,13	0,11	0,30	8,41	Moderate to high
	16.8.74	7,60	0,129	0,19	0,55	0,68	1,15	0,07	0,25	8,30	High
	12.9.74	7,70	0,138	0,21	0,57	0,44	1,17	0,15	0,29	8,35	High
	30.9.74	8,10	0,150	0,22	0,62	0,75	1,29	0,20	0,26	8,20	Moderate

† plus 0,33 meq/l $CO_3^{=}$