TRENDS IN WATER QUALITY OF SELECTED RIVERS IN THE SOUTH AFRICAN SUGAR INDUSTRY

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Abstract

Preliminary results are reported of a survey of water quality for 12 selected rivers in the South African sugar industry. The data set was made available by the Department of Water Affairs and covers the period from 1983 to 1993. The analytical data comprised pH, electrical conductivity, sodium, potassium, phosphorus, ammonium, nitrate, calcium, magnesium, chloride, bicarbonate and sulphate. Considerable spatial variability was observed in salinity/sodicity and nutrient levels within and between rivers. The survey revealed that the Mkuze river was moderately saline with a fairly high sodicity hazard, and that salinity levels in the lower Crocodile river have more than doubled since the last assessment was made in 1976. Of the other rivers, the Pongola, Umfolozi and Mhlatuze showed a moderate sodicity hazard implying that use for irrigation in the long term could lead to soil degradation and eventual yield decline on sensitive soils. Nutrient levels in several of the river systems were found to be highly variable but strongly dependent on rainfall events. Small increases in concentrations of N, P and K were noted for a number of rivers, but the peak concentrations of these nutrients were well below accepted world standards for drinking water.

Introduction

Good quality river water is not only important for successful irrigation of sugarcane but also for ensuring preservation of biological resources within, as well as outside, river systems, particularly in terms of man's increasing need for potable water supplies. There is a growing appreciation that the land, water, floral and faunal resources within river catchments are interrelated and interdependent, and that rivers provide fresh water and nutrients to wetlands, floodplains, estuaries and coastal waters.

Since the survey of water quality of major rivers in the northern areas was conducted in 1976 (Johnston, 1976), little use has been made of available analytical data for determining trends in river water quality. Water composition plays a significant role in determining the success or failure of crop production under irrigation. In 1986, a survey of eight important water sources used for irrigating sugarcane in northern Zululand showed that most of these water sources were saline and unsuitable for irrigating sugarcane (Culverwell and Swinford, 1986). Unlike sugarbeet, sugarcane is regarded as moderately sensitive to salinity (Maas, 1990). Irrigation with saline water induces water stress and soil salinity, with a marked reduction in crop yield when the threshold soil salinity level of 200 mS/m is exceeded (Von der Meden, 1966). Irrigating with sodic water induces soil sodicity, which results not only in reduced soil permeability, but also reduced cane growth through sodium toxicity (Johnston, 1978). Other problems that may be associated with the composition of irrigation water include high pH and bicarbonate values that can result in iron, manganese or zinc deficiency in the plant, leaf burn through a build up of chloride levels, stunted growth due to boron toxicity and lodging and delayed crop maturity due to high levels of nitrogen.

Recent concerns about the possible deterioration of water quality of rivers in the sugar industry, and the potential impact of nutrient losses from agricultural lands, led to this review of available analytical data from selected rivers in the sugar industry.

Procedure

Available analytical data for 12 selected rivers in the South African sugar industry were accessed from the Department of Water Affairs water quality database. The rivers studied were representative of the main extension areas in the sugar industry and included the Crocodile, Komati and Pongola rivers in the lowveld region, the Mkuze and Black Umfolozi in northern Zululand, the Mhlatuzi, Mlalazi and Tugela rivers in central and south Zululand, the Mvoti, Tongaat and Mhloti rivers on the north coast and the Mtamvuna river on the south coast. The locality of the rivers and the 16 sampling points are shown in Figure 1. The actual data set comprised chemical analyses from about 7 000 water samples collected between 1983 and 1993, on a fortnightly basis, from automated sampling stations. The analyses included pH, electrical conductivity (EC), total dissolved salts NO3, NH4, PO4, Cl, F, SO4, Na, K, Ca, Mg and Si. Water quality for irrigation was classified by taking both the salinity and sodicity levels into account. Salinity is measured as the electrical conductivity (EC) of water and refers to the total quantity of soluble salts comprising chlorides, sulphates, carbonates and bicarbonates of Na, Ca and Mg.

Sodicity refers to the quantity of sodium in relation to calcium and magnesium in water and is called the Sodium Adsorption Ratio or SAR. Interpretation of the EC and SAR values was based on criteria developed by the United States Department of Agriculture (USDA, 1954) which formed the basis of criteria developed by SASEX staff some years ago (Johnston, 1979).

Interpretation of nutrient concentrations was based on the maximun permissible levels used in pollution control as listed under General Standards in the Regulations of the Water Act.

Results and discussion

Mean annual chemical analyses of samples collected from the various rivers are reported in Appendix 1. A summary of water quality ratings for the rivers investigated is shown in Table 1. Examples of temporal changes in EC, SAR and nutrient concentrations of selected rivers are presented in Figures 2 - 5.

Salinity hazard

In terms of the USDA limits for salinity, the Komati, Mlalazi, Mtamvuma, Tongaat, Mvoti and Tugela rivers may be classified as very pure and with a low salinity hazard (<25 mS/m). At Karino, the Crocodile river also qualified as low salinity water but the hazard increased markedly downstream, with salinity levels being two to three times higher at Tenbosch than at Karino. The Pongola and Mhla-

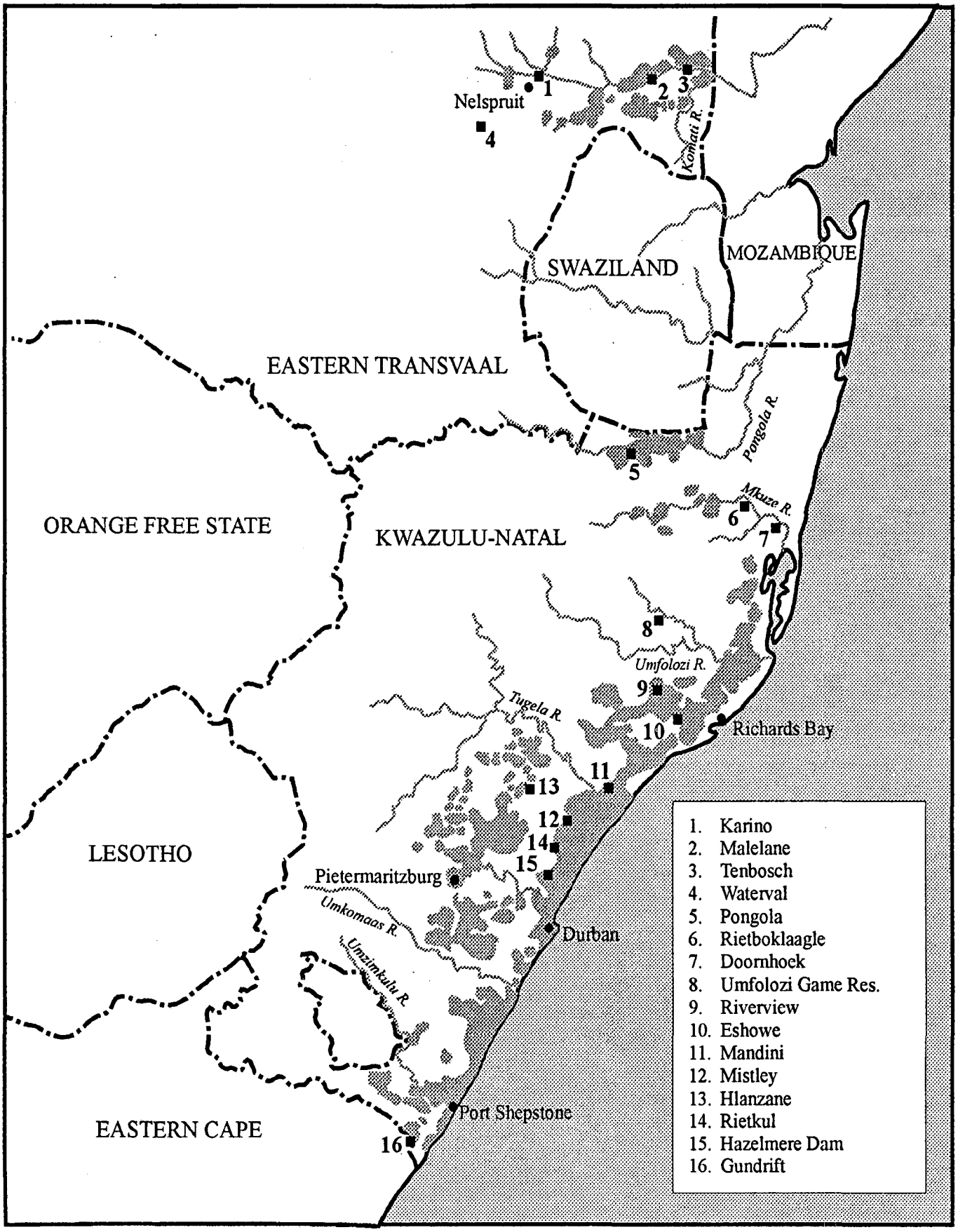

FIGURE 1 Location of selected rivers and sampling points.

tuze rivers were rated as medium salinity water (25-75 mS/m), while the Mkuze river increased from medium at Rietboklaagte to high salinity (75-225 mS/m) at Doornhoek. Considerable temporal variability was noted in the salinity levels of the Mkuze and Pongola rivers. The maximun EC levels were often 10 times higher than the minimum. The wide fluctuations in EC levels are illustrated for the Pongola and Umfolozi rivers in Figures 2 and 3 respectively.

Table 1

Summary of water quality ratings of selected rivers

River	No.	Sampling Locality	Period	Salinity hazard	Sodicity hazard	Chloride hazard	USDA rating	SASEX rating	Nutrients					
									N	P	K	S	Ca	Mg
Crocodile	1 2 3	Karino Malelane Tenbosch	1983/ 1993	Low/ Med	Low/ Med	Low	C2S1	A/B	Above average	Average	Average	Average	Average	Average
Komati	4	Waterval	1979/80 1990	Low	Low	Low	C1S1	A	Below average	Below average	Below average	Below average	Below average	Below average
Pongola	5	Mvutshini estate	1984/ 1988	Med	Med	Low	C1S1	B	Average	Below average	Average	Average	Average	Average
Mkuze	6 7	Rietboklaagle Doornhoek	1983/ 1993	Med/ High	High	Med/ High	C3S1	C/D	Average	Above average	Above average	Above average	Average	Average
Black Umfolozi	8	Umfolozi Game Reserve	1984/ 1985	Low/ Med	Med	Low	C2S1	B	Average	Average	Above average	Above average	Average	Average
Mhlatuze	9	Riverview	1983/ 1992	Med	Med	Med	C2S1	B	Below average	Average	Above average	Below average	Below average	Below average
Mlalazi	10	Eshowe	1984/ 1988/91	Low	Low	Low	C1S1	A	Below average	Below average	Above average	Below average	Below average	Below average
Tugela	11	Mandini	1983/ 1993	Low	Low	Low	C2S1	A	Above average	Above average	Above average	Average	Below average	Below average
Mvoti	12 13	Mistley Hlanzane	1983/85 1989/92	Low	Low	Low	C1S1	A	Below average	Below average	Below average	Average	Below average	Below average
Tongaat	14	Rietkuil	1983/86 1989/92	Low	Low	Low	C1S1	A	Above average	Average	Above average	Below average	Below average	Below average
Umhloti	15	Hazelmere dam	1985/ 1993	Low	Low	Low	C1S1	A	Above average	Below average	Above average	Below average	Below average	Below average
Mtamvuna	16	Gundrift	1983/ 1993	Low	Low	Low	C1S1	A	Below average	Below average	Below average	Below average	Below average	Below average

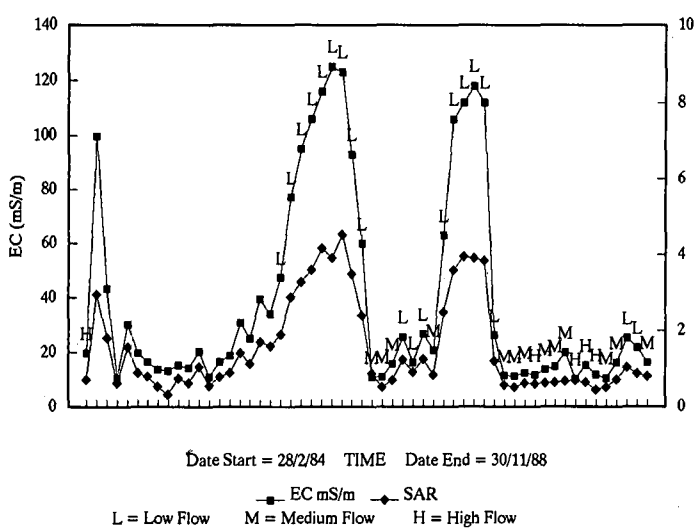

FIGURE 2 Fluctuation in EC and SAR levels with varying flow of the Pongola River.

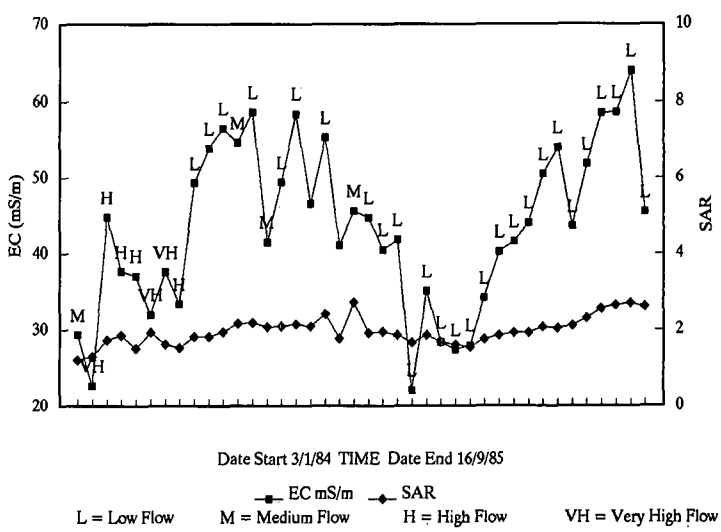

FIGURE 3 Fluctuation in EC and SAR levels with varying flow of the Black Umfolozi river.

High salinity levels can generally be correlated with the periods of low flow which occur during late winter and early spring. In the Mkuze river the salinity load at these times may reach levels of 400 mS/m and higher. This is equivalent to applying about 1,3 tons of salt per hectare per 50 mm of irrigation. Salinity levels in excess of 300 mS/m will exert an osmotic pressure of 100 kPa, which significantly inhibits water uptake. This is an insidious process since the irrigator may not be aware that yields are reduced.

Typical crop symptoms are wilting at fairly high moisture contents, poor growth, yellow spindly plants and grossly depressed yields. The extent of yield decline from soil salinisation over a 10 year period is illustrated by production data shown in Table 2 for a large estate in northern Zululand. Not even costly reclamation procedures such as drainage and dewatering pumps could correct the problem, and an area of 150 ha of formerly productive cane land had to be abandoned (Culverwell and Swinford, 1986).

It is difficult to comment on long term trends in salt build-up in our rivers, due to the considerable effects of temporal and spatial variability between sampling points. However, using data published by Johnston (1976) as a baseline, it is apparent that salinity levels in the lower Crocodile river have more than doubled over a period of 20 years, from 29 mS/m in 1972-73 to 52 mS/m in 1992-93 (Figure 4). Smaller increases were noted for the Komati, Pongola, Mkuze rivers and Black Umfolosi rivers.

Sodicity hazard

The effects of sodicity are potentially far more serious than salinity, since both the soil and the crop are adversely affected. Sodium has the effect of dispersing clay colloids, thereby destroying aggregation and pore structure. If mica and montmorillonite clay are present in the soil, they will tend to swell in response to the increase in sodium, and the dispersed clay colloids will block pores and channels and result in a decline in intake rates and internal drainage. A cyclic process is set in motion whereby even more rapid salt accumulation occurs, which in turn leads to further deterioration in the drainage rate.

In terms of available criteria most of the rivers sampled with the exception of the Mkuze, Pongola and Mhlatuze rivers, showed a low sodicity hazard. During periods of low flow the aforementioned rivers were moderately sodic, and irrigation with such water would be recommended only on freely draining soils.

Recent evidence has shown that the potential for the formation of surface seals or crusts in certain South African soils is very high, even in soils with SAR values as low as one (du Plessis and Shainberg, 1985). Surface crusts in turn can have a marked effect in reducing water intake rate and hydraulic conductivity in a soil (Agassi, Shainberg and Morin, 1981). Current criteria based on the USDA system do not discriminate sufficiently against sodic conditions in the low EC range in preventing permeability problems from developing.

Both Ayers and Westcott (1985) and the Canadian Water Quality Guidelines (1987) use combinations of SAR and EC to predict the permeability hazard of irrigation water. The principle is that, as SAR increases, EC also needs to increase in order to remain within the limits of an unlikely permeability hazard. The combinations of EC and SAR that were proposed by Ayers and Westcott (1985) to distinguish waters of nil, slight to moderate and severe permeability problems, are shown in Table 3. In terms of the data set the results imply that even chemically pure water sources with EC values less than 25 mS/m, but with a SAR of 1,5 and higher, could pose a serious permeability hazard on sensitive soils such as the Longlands, Kroonstad, Valsrivier and Escourt forms. Rivers in this category include the Mlalasi, Tongaat and Mvoti. According to these guidelines high SAR waters can be tolerated without reducing permeability, provided the EC levels are in the right range.

Chloride

Cl is an essential plant micronutrient that is readily transported with the soil water to be taken up by the plant roots and conveyed in the transpiration stream to accumulate in the leaves. When the accumulated concentration in the leaves exceeds crop tolerance, injury symptoms develop in the form of leaf burn, starting at the tips of leaves. The yield response of crops to chloride has yet to be further characterised. According to Maas (1990), sugarcane is moderately sensitive

Table 2

Yield decline on a 150 hectare irrigation scheme on the Hluhluwe river

Year	Ton/ha		Water quality assessment		
	Cane	Sucrose	ASAR	USDA	SASEX
1977	96	12,5	10,1	C3S2	D
1978	96	12,5	-	-	-
1979	84	10,4	-	-	-
1980	70	8,8	-	-	-
1981	66	8,2	16,9	C3S3	D
1982	49	6,2	13,9	C3S2	D
1983	37	4,4	12,2	C3S2	D
1984	35	4,1	10,2	C3S2	D

(After Culverwell and Swinford, 1986)

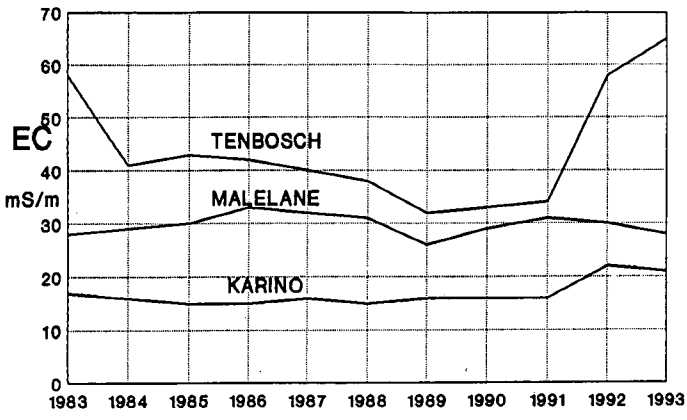

FIGURE 4 Variation in EC levels of the Crocodile river at three sampling points over a 10 year period.

Table 3

Permeability hazard in relation to EC and SAR

SAR	None	Slight to moderate	Severe
0-3	>70	70-20	<20
3-6	>120	120-30	<30
6-12	>190	190-50	<50
12-20	>290	290-130	<130
20-40	>500	500-290	<290

(After Ayers and Westcott, 1985)

to excess chloride in irrigation water. The Canadian Water Quality Guidelines (1987) limit the chloride concentrations of irrigation water to a maximum of 100 ppm for sensitive and 700 ppm for tolerant crops. Chloride concentrations found only in the Mkuze and Mhlatuze rivers (>75ppm), may be categorised as potentially problematical in terms of foliar damage with overhead sprinkler systems on very hot days.

Nutrient levels

Mean nutrient data given in Appendix 1, show that relatively large differences in the concentrations of nitrate, sulphate, chloride, calcium, magnesium and potassium were observed between the various rivers.

Nitrogen

For nitrate, the average levels between rivers varied fivefold, with the Crocodile, Tugela, Tongaat and Umhloti rivers showing the highest average concentrations of nitrate, whereas some of the lowest concentrations were obtained from the Komati, Mvoti and Mtamvuna rivers. Nitrate levels at Karino on the Crocodile river reached the highest mean concentration recorded for the upper reaches. The levels progressively declined downstream and were consistently lower at Tenbosch compared with Malelane (Figure 5).

The decline in nitrate concentrations is somewhat unusual, and is probably related to N uptake by the water hyacinth growing in the river between Karino and Malelane. It is interesting that the relatively high levels of nitrate at Karino are about three to four orders of magnitude higher than nitrate concentrations reported for the Herbert River in northern Queensland (Bramley *et al.*, 1994). The mean value of 1,02 ppm N covering the 1983 to 1993 period was also slightly higher than the maximum concentration of 1 ppm allowed in waste water disposal. The evidence suggested contamination of the river upstream from Karino towards Nelspruit, by activities other than agriculture. If leaching of nitrates from N fertilisers was a factor then nitrate concentrations would have increased downstream, particularly between Malelane and Tenbosch, where the bulk of the sugarcane is grown. Relatively low ammonium concentrations occured in most rivers, and mean concentrations ranged from a low of 0,05 ppm for the Tongaat river to a high level of 0,29 ppm for the Tugela river. No consistent downstream pattern was found, neither was a consistent seasonal trend in ammonium levels evident.

Phosphate

With the exception of the Tugela river and upper Mvoti rivers, P concentrations by Australian standards were relatively low in most of the other rivers. As in the case of nitrate, there was evidence that the highest P concentrations coincided with maximum river discharge. Longitudinal differences in P concentration varied among rivers, the higher levels of P occuring at downstream sampling points on the Mkuze and Mvoti rivers and little downstream change noted for the Crocodile river. Comparative analysis of data over a 10 year period showed no decline or build-up in P levels, suggesting that pollution from P fertiliser is unlikely to be a problem.

Potasssium

Some of the highest concentrations of K, measured in the Mkuze, Umfolozi, Mhlatuze and Tugela rivers, were comparable with levels measured in Australian rivers. In general, concentrations of K seemed less affected by rainfall events than those of nitrate and phosphate. Comparison of K levels between upstream and downstream sampling points on the Crocodile (Figure 6), Mkuze and Mvoti rivers showed increased K build-up which may reflect differences in the geology of subcatchments draining below the sampling points, as well as some K derived from fertiliser sources. The increases in all instances were accompanied by marked enhancement of chloride levels, lending support to the contention that muriate of potash (KCl) was the most likely source of contamination. In recent years K usage in the Eastern Transvaal has increased in response to an increase in soil threshold values, particularly on winter cycle cane (Donaldson *et al.*, 1990). The data also suggests that some of these increases may have originated from irrigation drainage associated with over-irrigation.

Other nutrients

Although nutrients such as Ca and Mg in irrigation water are potentially beneficial to sugarcane, the pollution hazard of these elements is considered relatively minor. Latitudinal differences exist between the Ca and Mg levels between the rivers in the northern and southern parts of the industry. In general the northern rivers contained three to four times more Ca and Mg than the central and southern rivers. There was also a tendency for Ca concentrations to be about 20% higher than Mg levels. However, a reversal in the Ca:Mg ratio was noted for the Pongola river, due probably to the catchment areas characterised by Mg rich serpentite rocks of the Swaziland Basic Rock System (du Toit, 1954). Sulphate levels also showed considerable latitudinal variation with higher concentrations of sulphate occuring in the northern rivers compared with a tendency for lower sulphate concentrations in the southern rivers.

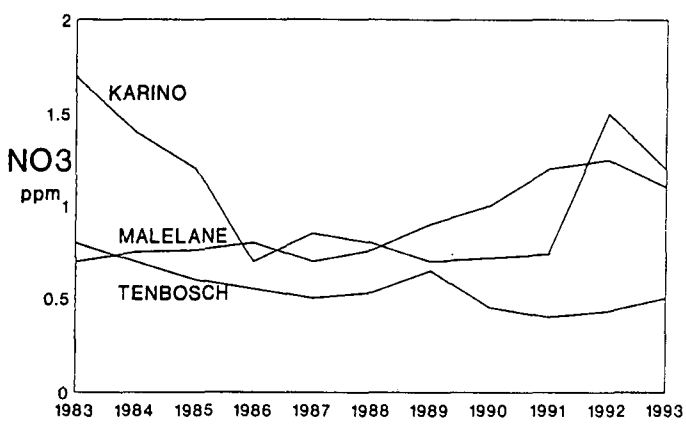

FIGURE 5 Variation in nitrate concentration of the Crocodile river at three sampling points.

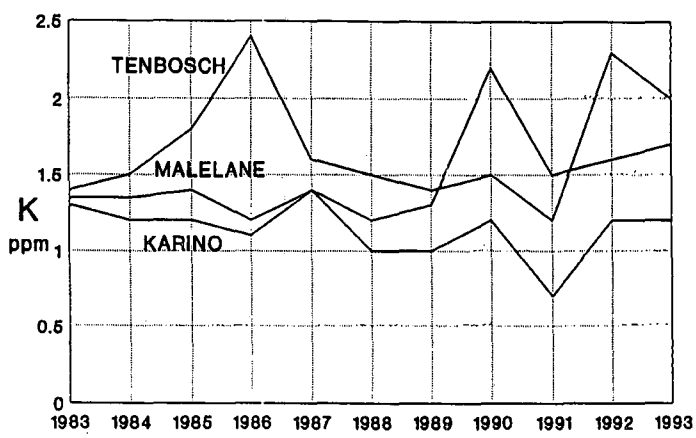

FIGURE 6 Variation in potassium concentration of the Crocodile river at three sampling points.

Conclusions

Of the 12 rivers investigated it may be concluded that the composition of the Mkuze river shows the greatest contrast with the other rivers, not only in of terms longitudinal variations downstream, but also in terms of seasonal variations between winter and summer months. The salinity/sodicity hazard of this river is high and appropiate measures such as artificial soil drainage would be needed in soils with impeded drainage problems. The Pongola and Mhlatuze rivers are associated with medium salinity/sodicity levels which, with continued irrigation, could pose a hazard to soil permeablilty in the long term.

Recent international advances in the development of water quality criteria indicate that the potential effect of SAR on soil permeability due to low electrolyte concentrations is being underestimated. A number of rivers classified as A quality water would on the basis of a low EC value, and an SAR value below 1,5 would be rated as B quality. Rivers such as the Mlalasi, Mvoti and Tongaat fall into this category. Interim guidelines that include more sensitive SAR class intervals could form the basis of a revised system for SASEX (Table 4). However, further work will be needed to take the soil factor into account. In terms of future work, there is also the need to develop a model for inclusion into the CANEGRO model, that can predict the effect of water quality on the matric potential of the soil water as well as predicting the impact of sodicity on soil permeability and the soil water balance. Suitable management strategies will also need to be devised to counter the problem of low electrolyte concentration in irrigation water. Previous attempts at treating irrigation water with sulphur dioxide proved to be largely impracticable. The use of surface applications of gypsum has proved benficial in minimising crust formation under rainfed conditions (Dewey and Meyer 1989). The treatment of irrigation water with gypsum using the Australian technique of dissolvinator plants is an option which still requires validation under local conditions (Ham, 1986).

Table 4

Summary of proposed interim guidelines for assessing water quality

Water quality	Water quality class			
	Class 1	Class 2	Class 3	Class 4
Salinity (EC mS/m)	<50	50-100	100-200	>200
Sodicity (SAR)	<3	3-5	5-10	>10

With regard to the second part of the investigation, the assessment of available data showed no evidence of large scale nutrient enrichment. Increases in the concentrations of inorganic nutrients such as N, P and K were found in several river systems, but the peak concentrations of these nutrients were well below accepted world standards for drinking water. Nutrient levels in the various rivers were found to be highly variable and strongly affected by rainfall events, probably from a combination of surface run-off and groundwater flow feeding into rivers. Future work should focus on the Australian approach of using river discharge data to determine nutrient loading and estimates of the amounts of fertiliser nutrients lost from catchment areas (Bramley, 1994). This should enable a better evaluation of the effects of nutrient loading on possible environmental degradation in near-shore coastal environments.

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Appendix 1: Variation in chemical composition of selected rivers.

SITE	Year	pH	Total diss salts	EC mS/m	SAR	EEC mS/m	ASAR	WATER QUALITY (EEC)	WATER QUALITY (EC)	Na mg/l	Mg mg/l	Ca mg/l	F mg/l	Cl mg/l	NO^3+NO^2 mg/l	SO4 mg/l	PO4 P mg/l	TAL as CaCO3 mg/l	Si mg/l	K mg/l	$NH4$ N mg/l
MTAMVUNA RIVER AT GUNDRIFT/MTAMVUNA	1983	6.9	65	9.1	0.64	2.94	0.64	A	A	6	5	5	0.1	6	0.18	10	0.01	29	7.5	0.6	0.03
	1984	7.1	89	10.7	0.99	3.46	0.99	A	A	10	5	7	0.1	14	0.34	12	0.02	32	8.1	0.8	0.06
	1985	7.2	69	9.0	0.64	2.91	0.64	A	A	6	5	5	0.1	11	0.25	6	0.01	29	7.9	0.4	0.06
	1986	7.0	60	8.7	0.64	2.81	0.64	A	A	6	5	5	0.1	9	0.28	3	0.01	26	7.8	0.5	0.07
	1987	6.7	55	10.2	0.71	3.29	0.71	A	A	6	4	4	0.1	8	0.42	6	0.02	21	7.6	0.6	0.07
	1988	6.9	61	14.1	0.64	4.55	0.64	A	A	6	5	5	0.2	8	0.45	3	0.02	26	8.2	0.5	0.06
	1989	7.6	73	10.4	0.75	3.36	0.75	A	A	7	5	5	0.1	9	0.27	3	0.02	35	8.0	0.6	0.06
	1990	7.4	71	9.4	0.64	3.04	0.64	A	A	6	5	5	0.1	8	0.27	5	0.01	34	7.8	0.6	0.04
	1991	7.6	63	9.6	0.53	3.10	0.53	A	A	5	5	5	0.1	7	0.31	7	0.02	28	7.3	0.6	0.07
	1992	7.8	71	10.4	0.53	3.36	0.53	A	A	5	5	5	0.2	5	0.17	6	0.03	36	7.3	0.6	0.04
	1993	7.7	73	9.7	0.53	3.13	0.53	A	A	5	5	5	0.2	6	0.14	8	0.05	36	6.2	0.6	0.04
	Mean	7.3	68	10.1	0.66	3.27	0.66	A	A	6	5	5	0.1	8	0.28	6	0.02	30	7.6	0.6	0.05

SITE	Year	pH	Total diss salts	EC mS/m	SAR	EEC mS/m	ASAR	WATER QUALITY (EEC)	WATER QUALITY (EC)	Na mg/l	Mg mg/l	Ca mg/l	F mg/l	Cl mg/l	NO^3+ NO^2 mg/l	SO4 mg/l	PO4 P mg/l	TAL as CaCO3 mg/l	Si mg/l	K mg/l	NH4 N mg/l
TONGATI RIVER AT RIET KUIL	1983	6.5	99	15.7	2.16	5.07	2.16	A	A	19	4	5	0.2	24	0.32	9	0.02	29	9.4	1.8	0.03
	1984	6.5	87	14.5	2.25	4.68	2.25	A	A	18	4	3	0.1	28	0.80	9	0.05	17	9.6	1.6	0.05
	1985	6.6	90	14.5	2.21	4.68	2.21	A	A	18	3	5	0.1	27	0.73	8	0.02	20	10.0	1.5	0.05
	1986	7.0	88	14.8	2.59	4.78	2.59	A	A	20	3	4	0.1	28	0.61	4	0.03	21	9.8	1.6	0.06
	1987																				
	1988																				
	1989	7.4	85	14.9	2.61	4.81	2.61	A	A	19	3	3	0.1	27	0.87	5	0.03	18	10.0	1.8	0.05
	1990	7.4	85	14.5	2.47	4.68	2.47	A	A	18	3	3	0.2	26	0.76	5	0.02	20	9.7	1.7	0.06
	1991	7.4	76	14.2	2.20	4.59	2.20	A	A	16	3	3	0.1	25	0.90	6	0.02	15	9.1	1.4	0.05
	1992	7.6	90	16.4	2.47	5.30	2.47	A	A	18	3	3	0.2	23	0.34	8	0.05	25	9.5	2.0	0.05
	1993																				
	Mean	7.1	88	14.9	2.37	4.82	2.37	A	A	18	3	4	0.1	26	0.67	7	0.03	21	9.6	1.7	0.05
HAZELMERE DAM: NEAR DAM WALL	1983																				
	1984																				
	1985	7.2	118	19.3	2.26	7.40	2.26	A	A	22	5	6	0.1	33	1.05	10	0.01	29	9.1	1.9	0.05
	1986	7.1	112	19.3	2.26	7.40	2.26	A	A	22	5	6	0.2	30	0.59	6	0.01	32	9.1	1.7	0.06
	1987	6.8	105	18.2	2.13	6.97	2.13	A	A	20	5	5	0.1	27	0.76	8	0.03	29	8.6	1.8	0.07
	1988	6.5	86	16.1	2.02	6.17	2.02	A	A	17	4	4	0.1	24	1.05	8	0.03	18	9.0	1.3	0.07
	1989																				
	1990	7.6	108	16.4	1.85	6.28	1.85	A	A	18	5	6	0.2	25	0.40	4	0.01	37	9.4	1.4	0.08
	1991	7.7	92	15.7	1.82	6.02	1.82	A	A	16	4	5	0.1	23	0.27	2	0.01	33	9.6	1.4	0.07
	1992	7.7	123	18.8	1.89	7.20	1.89	A	A	20	6	7	0.2	25	0.38	3	0.01	47	8.4	1.9	0.10
	1993	7.8		21.7	2.07	8.32	2.07	A	A	23	7	7	0.1	31	0.46	1	0.01	54	8.8	2.4	
	Mean	7.3	106	18.2	2.04	6.97	2.04	A	A	20	5	6	0.1	27	0.62	5	0.02	35	9.0	1.7	0.07
MVOTI RIVER AT MISTLEY	1983	6.4	83	12.3	0.67	4.26	0.67	A	A	7	5	8	0.1	5	0.03	24	0.01	28	4.8	1.1	0.05
	1984																				
	1985	6.8	77	11.3	0.87	3.92	0.87	A	A	8	4	6	0.0	14	0.08	8	0.03	29	7.3	0.9	0.05
	1986	6.7	69	10.5	0.76	3.64	0.76	A	A	7	4	6	0.1	10	0.10	7	0.03	28	6.3	1.4	0.06
	1987	6.6	67	12.9	0.87	4.47	0.87	A	A	8	4	6	0.1	11	0.15	10	0.02	22	5.3	1.8	0.06
	1988	6.7	76	12.7	0.79	4.40	0.79	A	A	8	5	7	0.1	8	0.13	10	0.01	31	6.8	1.1	0.05
	1989	7.4	115	16.9	1.09	5.86	1.09	A	A	13	7	10	0.1	13	0.26	23	0.03	41	7.0	1.2	0.05
	1990	7.5	75	11.2	0.72	3.88	0.72	A	A	7	5	6	0.1	10	0.12	5	0.03	33	5.6	0.8	0.05
	1991	7.5	71	11.6	0.76	4.02	0.76	A	A	7	4	6	0.1	10	0.06	7	0.02	29	6.0	0.8	0.05
	1992	7.2	83	12.1	0.60	4.19	0.60	A	A	6	5	7	0.2	5	0.01	5	0.02	44	5.8	0.7	0.14
	1993	3.8	526	80.2	0.46	27.79	0.46	A	B	14	37	80	0.2	6	0.03	385	0.02	20.6	2.9	0.1	
	Mean	6.7	124	19.2	0.76	6.64	0.76	A	A	9	8	14	0.1	9	0.10	48	0.02	31	5.8	1.0	0.06
MVOTI RIVER AT HLANZANE	1983	7.5	194	32.5	3.09	11.26	3.09	A	A	37	7	10	0.4	36	0.48	10	0.08	73	6.8	2.4	0.05
	1984	7.0	113	17.5	1.99	6.06	1.99	A	A	20	5	7	0.2	28	0.44	10	0.03	33	8.4	1.5	0.04
	1985	7.4	162	27.1	2.42	9.39	2.42	A	A	29	7	10	0.2	34	0.36	13	0.07	55	8.4	1.8	0.18
	1986			26.8																	
	1987																				
	1988																				
	1989	7.8	165	25.4	2.34	8.80	2.34	A	A	28	7	10	0.2	40	0.93	8	0.02	55	9.9	2.2	0.06
	1990	7.7	148	23.1	2.23	8.00	2.23	A	A	25	6	9	0.2	34	0.57	5	0.02	52	8.5	1.6	0.05
	1991	7.7	159	26.0	2.26	9.01	2.26	A	A	27	7	10	0.2	37	0.73	7	0.02	54	8.8	1.8	0.05
	1992	8.0	282	40.7	3.09	14.10	3.15	A	A	49	12	18	0.3	65	0.39	11	0.02	101	8.4	3.1	0.04
	1993																				
	Mean	7.6	175	27.4	2.49	9.49	2.49	A	A	31	7	11	0.2	39	0.56	9	0.04	60	8.5	2.1	0.07
TUGELA RIVER AT MANDINI	1983	7.3	198	28.6	1.36	5.85	1.36	A	A	21	9	21	0.4	17	1.01	14	0.12	88	6.8	2.2	0.10
	1984	7.0	163	20.8	1.27	4.25	1.27	A	A	18	8	17	0.4	21	0.49	24	0.16	57	7.6	2.2	0.42
	1985	7.8	213	29.3	1.40	5.99	1.45	A	A	23	12	21	0.2	23	0.40	18	0.05	92	6.9	2.1	0.28
	1986	7.6	192	25.3	1.30	5.17	1.30	A	A	20	10	19	0.2	20	0.19	17	0.05	84	5.4	2.0	0.43
	1987	7.3	168	25.8	1.17	5.28	1.17	A	A	17	9	17	0.2	17	0.33	13	0.03	75	6.0	1.7	0.09
	1988	7.1	151	26.8	1.22	5.48	1.22	A	A	17	8	16	0.3	19	0.33	10	0.03	62	6.9	1.6	0.14
	1989	7.8	252	30.6	1.68	6.26	1.92	A	A	28	12	22	0.3	28	1.39	23	0.23	106	6.4	2.2	0.27
	1990	7.8	202	24.9	1.37	5.09	1.37	A	A	21	10	19	0.3	22	0.25	13	0.04	94	5.4	1.9	0.15
	1991	8.0	203	22.7	1.52	4.64	1.52	A	A	23	10	18	0.3	21	0.48	15	0.10	90	5.8	2.1	0.98
	1992	8.1	211	20.3	1.50	4.15	1.57	A	A	23	10	19	0.3	17	0.36	18	0.07	98	5.0	2.2	0.27
	1993	8.1	220	18.7	1.30	3.82	1.35	A	A	21	10	23	0.3	14	0.51	21	0.05	104	4.8	2.3	0.09
	Mean	7.6	198	24.9	1.37	5.09	1.37	A	A	21	10	19	0.3	20	0.52	17	0.08	86	6.1	2.0	0.29

SITE	Year	pH	Total diss salts	EC mS/m	SAR	EEC mS/m	ASAR	WATER QUALITY (EEC)	WATER QUALITY (EC)	Na mg/l	Mg mg/l	Ca mg/l	F mg/l	Cl mg/l	NO^{3+} NO^{2} mg/l	SO4 mg/l	PO4 P mg/l	TAL as CaCO3 mg/l	Si mg/l	K mg/l	NH4 N mg/l
CROCODILE RIVER AT KARINO	1983	7.2	122	16.9	0.84	9.90	0.84	A	A	9	10	13	0.2	7	1.62	22	0.08	43	9.1	1.2	0.04
	1984	7.0	93	16.0	0.58	9.37	0.58	A	A	7	7	10	0.1	10	1.37	22	0.03	27	7.8	1.1	0.33
	1985	7.3	97	14.9	0.49	8.73	0.49	A	A	6	7	11	0.1	9	1.15	13	0.01	36	7.8	1.1	0.12
	1986	7.2	97	14.5	0.48	8.49	0.48	A	A	6	8	10	0.1	7	0.68	9	0.03	44	7.4	1.0	0.09
	1987	7.0	96	14.9	0.50	8.73	0.50	A	A	6	7	10	0.1	8	0.86	10	0.02	41	7.8	1.4	0.12
	1988	6.9	96	14.7	0.51	8.61	0.51	A	A	6	7	9	0.1	8	0.80	8	0.03	44	7.3	1.0	0.16
	1989	7.7	99	15.0	0.58	8.79	0.58	A	A	7	8	9	0.2	8	0.87	8	0.02	46	7.6	1.0	0.15
	1990	7.8	104	15.2	0.48	8.90	0.48	A	A	8	8	10	0.2	10	0.71	8	0.02	47	7.5	1.2	0.10
	1991	7.8	98	15.7	0.40	9.19	0.40	A	A	5	8	10	0.2	10	0.72	10	0.02	42	7.7	0.8	0.14
	1992	7.9	134	21.9	0.41	12.83	0.41	A	A	6	11	14	0.2	9	1.50	18	0.02	56	5.8	1.2	0.08
	1993	7.8	136	21.3	0.55	12.47	0.55	A	A	8	10	15	0.2	11	1.16	19	0.02	55	7.2	1.2	0.05
	Mean	7.4	107	16.5	0.51	9.64	0.51	A	A	7	8	11	0.2	9	1.02	13	0.03	44	7.5	1.1	0.13
CROCODILE RIVER AT TEN BOSCH/K NAT P	1983	7.8	497	62.7	2.82	36.72	4.76	A	B	67	31	34	0.4	50	0.89	32	0.03	231	19.2	1.3	0.03
	1984	7.7	270	39.8	1.84	23.31	2.26	A	A	34	19	20	0.3	27	0.79	29	0.02	112	11.5	1.4	0.04
	1985	8.3	360	44.1	2.25	25.83	3.18	A	A	46	24	23	0.3	32	0.69	24	0.01	169	12.0	1.8	0.06
	1986	7.9	294	41.4	1.95	24.25	2.57	A	A	38	19	20	0.3	24	0.54	20	0.01	141	11.8	1.0	0.09
	1987	7.7	282	38.8	1.81	22.72	2.41	A	A	33	18	20	0.3	23	0.54	18	0.02	137	11.9	1.3	0.06
	1988	7.6	254	35.3	1.67	20.67	2.08	A	A	29	17	17	0.3	21	0.55	16	0.02	123	10.5	1.3	0.06
	1989	8.0	238	30.8	1.58	18.04	1.80	A	A	26	15	16	0.3	19	0.52	14	0.03	117	10.2	1.2	0.06
	1990	8.4	258	33.0	1.60	19.33	1.98	A	A	28	17	18	0.3	21	0.41	15	0.01	128	10.7	1.2	0.05
	1991	8.1	245	32.3	1.59	18.92	1.97	A	A	27	16	17	0.3	18	0.38	14	0.01	124	10.6	1.1	0.04
	1992	8.3	464	58.9	2.54	34.50	4.07	A	B	57	27	31	0.4	31	0.47	29	0.02	235	14.4	1.8	0.09
	1993	8.4	512	65.8	2.77	38.54	4.68	A	B	66	30	36	0.5	48	1.02	36	0.03	238	14.3	1.7	0.08
	1994	8.3	362	41.0	2.07	24.01	2.92	A	A	42	21	27	0.4	31	0.48	35	0.03	166	14.1	2.0	0.08
	Mean	8.0	336	43.7	2.04	25.57	2.95	A	A	41	21	23	0.3	29	0.61	24	0.02	160	12.6	1.4	0.06
CROCODILE RIVER AT MALELANE BRIDGE / K NAT P	1983																				
	1984																				
	1985																				
	1986	7.9	235	33.0	1.28	19.33	1.46	A	A	23	19	17	0.2	13	0.87	15	0.02	118	10.9	1.0	0.09
	1987	7.4	219	30.1	1.28	17.63	1.46	A	A	22	17	16	0.2	14	0.78	14	0.03	108	10.2	1.3	0.06
	1988																				
	1989	8.2	194	24.8	1.00	14.52	1.05	A	A	16	15	14	0.2	11	0.91	16	0.03	96	9.1	0.9	0.05
	1990	7.8	238	31.9	1.09	18.68	1.36	A	A	19	16	19	0.3	15	0.55	15	0.04	122	10.6	2.1	0.04
	1991	8.0	226	30.9	1.23	18.10	1.40	A	A	21	17	16	0.2	15	1.13	16	0.03	110	10.1	1.4	0.06
	1992																				
	1993																				
	Mean	7.9	222	30.1	1.18	17.65	1.34	A	A	20	17	16	0.2	14	0.85	15	0.03	111	10.2	1.3	0.06
MHLATUZE RIVER AT RIVERVIEW 11459	1983	7.9	628	86.7	6.57	35.34	8.54	B	B	139	25	26	0.4	170	0.18	21	0.02	195	8.3	3.5	0.04
	1984	7.4	273	39.9	3.83	16.26	3.83	A	A	58	13	13	0.3	86	0.57	34	0.07	55	9.4	2.9	0.11
	1985	7.6	239	36.0	3.39	15.49	3.39	A	A	48	11	12	0.2	65	0.37	11	0.03	72	9.5	2.5	0.05
	1986	7.9	373	56.0	4.54	22.83	5.40	B	B	78	16	18	0.3	93	0.22	15	0.01	124	9.6	2.3	0.06
	1987	7.5	386	61.8	4.77	25.19	5.20	B	B	82	16	18	0.3	103	0.32	16	0.03	120	8.9	2.5	0.07
	1988	7.0	172	34.8	2.80	14.18	2.80	A	A	34	8	9	0.2	44	0.42	7	0.05	54	8.2	1.9	0.07
	1989	7.9	236	33.9	3.12	13.82	3.12	A	A	43	10	12	0.2	53	0.27	8	0.02	87	8.9	1.9	0.06
	1990	8.0	265	35.4	3.67	14.43	3.67	A	A	52	11	12	0.2	67	0.36	9	0.02	91	8.3	2.1	0.07
	1991	8.1	323	38.7	4.12	15.77	4.16	A	A	65	13	16	0.3	81	0.21	9	0.02	113	9.1	1.9	0.04
	1992	8.1	275	27.9	3.75	11.37	3.75	A	A	54	11	13	0.3	64	0.15	13	0.03	100	8.2	2.3	0.04
	1993																				
	Mean	7.7	317	45.3	4.06	18.47	4.20	A	A	65	13	15	0.3	83	0.31	14	0.03	101	8.8	2.4	0.06
MLALAZI RIVER AT ESHOWE	1983																				
	1984	6.1	100	18.4	2.01	4.03	2.01	A	A	20	6	5	0.1	38	0.28	14	0.02	12	2.3	2.0	0.14
	1985			16.2																	
	1986																				
	1987			24.8																	
	1988	5.8	75	21.5	1.91	4.71	1.91	A	A	16	4	4	0.1	33	0.30	5	0.02	8	4.0	1.9	0.17
	1989	7.1	90	17.8	2.14	3.90	2.14	A	A	18	4	4	0.1	40	0.36	5	0.02	12	3.9	2.2	0.22
	1990	7.5	142	25.3	3.31	5.54	3.31	A	A	33	6	5	0.1	64	0.18	7	0.02	20	3.5	2.5	0.11
	1991	7.5	86	17.2	2.02	3.77	2.02	A	A	17	4	4	0.1	35	0.17	7	0.02	13	3.4	2.2	0.11
	1992																				
	1993																				
	Mean	6.8	99	20.2	2.28	4.42	2.28	A	A	21	5	4	0.1	42	0.26	8	0.02	13	3.4	2.2	0.15
MKUZE RIVER AT RIETBOKLAAGTE	1983	7.6	668	77.4	4.88	44.70	6.35	B	B	122	38	31	0.4	133	0.49	135	0.03	183	10.5	2.3	0.05
	1984	7.3	333	51.6	1.86	29.80	1.86	A	B	39	19	35	0.3	36	0.33	145	0.01	45	8.1	1.7	0.05
	1985	7.7	338	46.5	2.25	26.85	2.49	A	A	45	19	29	0.4	43	0.24	102	0.01	79	7.5	1.6	0.11
	1986	7.3	301	46.2	1.69	26.68	1.73	A	A	34	18	31	0.5	27	0.07	112	0.01	63	5.9	1.8	0.06
	1987	6.9	185	29.4	1.27	16.98	1.27	A	A	20	11	19	0.3	16	0.16	69	0.01	38	6.6	1.7	0.07
	1988	6.7	158	27.4	1.35	15.82	1.35	A	A	19	9	15	0.3	17	0.17	52	0.04	36	8.2	1.4	0.07
	1989	7.9	259	36.3	1.62	20.96	1.62	A	A	29	14	25	0.3	19	0.11	91	0.01	65	7.0	1.4	0.05
	1990	7.6	276	38.0	1.69	21.94	1.74	A	A	31	15	26	0.3	25	0.08	86	0.22	74	6.4	1.7	0.09
	1991	7.6	266	41.8	1.72	24.14	1.72	A	A	31	14	26	0.3	19	0.12	103	0.01	58	6.7	1.4	0.04
	1992																				
	1993																				
	Mean	7.4	309	43.8	2.04	25.32	2.19	A	A	41	17	26	0.3	37	0.20	99	0.04	69	7.4	1.7	0.07

SITE	Year	pH	Total diss salts	EC mS/m	SAR	EEC mS/m	ASAR	WATER QUALITY (EEC)	WATER QUALITY (EC)	Na mg/l	Mg mg/l	Ca mg/l	F mg/l	Cl mg/l	NO^3+ NO^2 mg/l	SO4 mg/l	PO4 P mg/l	TAL as CaCO3 mg/l	Si mg/l	K mg/l	NH4 N mg/l
MKUZE RIVER AT DOORNHOEK	1983	8.1	1396	108.8	10.77	62.83	21.10	D	D	333	58	48	0.3	398	0.97	205	0.07	331	14.8	3.1	0.05
	1984	7.7	499	72.6	2.98	41.92	3.82	A	B	73	28	44	0.4	100	0.51	139	0.02	90	8.6	2.1	0.07
	1985																				
	1986																				
	1987	7.6	457	69.3	3.37	40.02	4.31	A	B	75	24	35	0.4	102	0.16	80	0.01	113	7.2	2.1	0.06
	1988	7.4	419	69.9	3.32	40.36	4.28	A	B	70	23	29	0.4	88	0.21	62	0.23	118	8.0	1.8	0.05
	1989	8.0	511	73.3	3.48	42.33	5.15	B	B	81	27	37	0.4	104	0.23	104	0.02	127	7.6	2.2	0.05
	1990																				
	1991																				
	1992	8.4	732	104.4	4.57	60.29	6.40	B	B	125	42	43	0.4	177	0.91	108	0.02	188	7.9	2.8	0.06
	1993	8.3	482	65.9	3.26	38.06	4.85	A	B	73	24	36	0.4	75	0.39	76	0.04	159	7.5	2.7	0.07
	Mean	7.9	642	80.6	4.53	46.54	6.23	B	B	119	32	39	0.4	149	0.48	111	0.06	161	8.8	2.4	0.06