THE GEOLOGY AND GEOHYDROLOGY

OF THE MAKATINI FLATS,

WITH SPECIAL REFERENCE TO THE PROBLEMS OF

SALINIZATION AND WATERLOGGING

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TABLES

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THE GEOLOGY AND GEOHYDROLOGY OF THE MAKATINI FLATS, WITH SPECIAL REFERENCE TO THE PROBLEMS OF SALINIZATION AND WATERLOGGING

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1. Introduction

At the request of the State Attorney in the expropriation case concerning the Ndumu Farms (Agricultural Development Corporation (Pty.) Ltd. vs. the Minister of Agricultural Credit and Land Tenure), I visited the Makatini Flats below the J.G. Strydom Dam at Jozini during the period from the 10th to 16th May, 1967, to study the geology and geohydrology of the area and to aquaint myself with the physical conditions prevailing there. I was accompanied during my visit by Mr. E. Verster of Soil Surveys, Department of Agricultural Technical Services. A meeting was held on the 11th May with Mr. R.F. Phelines, Resident Engineer at Jozini, during which technical aspects of the proposed irrigation scheme on the Makatini Flats were discussed. On the 15th, I paid a visit to the Pongola Irrigation Settlement to examine the geological and geohydrological conditions in that area and to draw a comparison between the two areas visited.

It was originally intended that the information collected during the visit would be utilised by the State Attorney during the legal proceedings of the expropriation case. However, during discussions held at Pietermaritzburg it became evident that from certain legal viewpoints the hydrological and chemical data already available were not sufficiently comprehensive and were not representative of the area as a whole. It was consequently decided to drill a series of bore-holes, suitably spaced, into the Cretaceous sediments on the Makatini Flats, with the object of demonstrating conclusively that the groundwaters harboured in these rocks are highly saline throughout the entire area. Altogether three bore-holes were accordingly sited in the northern, central and southern parts of the area. In September, 1967, while drilling was still in progress at the first site selected in the northern part of the area, the case was settled out of court and litigation was suspended. As a result of this development, drilling was immediately stopped and the final report was never submitted. However, in view of the time spent on this work, and the additional data that came to hand concerning the problems of salinization and waterlogging in the area as a whole, it was decided to complete a brief account of the information collected.

2. GEOLOGY

The geology of the Makatini Flats is described in detail by Meyer (1951) and by Meyer and Engelbrecht (1951). Only a short description of the formations will therefore be given here.

The geology of the area is shown on the accompanying geological map, scale 1:250,000 (Folder 1). A summary of the principal geological formations present in the area is given in Table 1.

Table 1.- Geological Succession on Makatini Flats

Tertiary to Recent		Alluvium, river terraces, surface limestone, white sand and red sandstone.
Cretaceous System	Upper Cretaceous	Clayey sandstone, sandy shale, limestone, marl.
	Lower Cretaceous	Basal conglomerate, clayey sandstone, sandy shale, limestone.
Karoo System	Stormberg Series Lebombo Stage	Rhyolite, dacite, agglomerate, tuff, volcanic breccia.

2.1. The Karoo System.- The Karoo System is represented in the area by the Lebombo and Drakensberg Stages of the Stormberg Series. The Drakensberg Stage consists essentially of basalt and underlies the undulating bush-clad area to the west of the Lebombo Range. The Lebombo Stage underlies the partially dissected Lebombo range and consists of dacite and rhyolite, volcanic tuff and breccia, which dip at an angle of 15 - 24° to the east.

2.2. The Cretaceous System.- Sediments of the Cretaceous System occupy the coastal plain extending eastwards from the foot of the Lebombo Range. Two divisions have been recognised in the area, both dipping at an angle of 3 to 5 degrees to the east.

The Lower Cretaceous.- This division, which consists of basal conglomerates, interspersed with clayey sandstones and sandy clays, follows unconformably upon the dacite and rhyolite of the Lebombo Range. They are probably of terrestrial and/or estuarine origin.

As will be seen from the geological map. The division forms a belt of country running northwards along the base of the range from the Pongola River in the south to the Usutu River in the north.

The Upper Cretaceous.- This division follows conformably on the Lower Cretaceous and consists chiefly of clayey sandstone, sandy shale, limestone and marl. These sediments are all of marine origin, as proved by the presence of numerous marine fossils in them. The Upper Cretaceous sediments form a wide belt of country running parallel to the tract underlain by the Lower Cretaceous further to the west. The Pongola River, after emerging from Pongola Poort, traverses the Lower Cretaceous and then assumes a northward course somewhere near the centre of the belt of country underlain by the Upper Cretaceous sediments. It is important to note that for the greater part of its course, the Pongola, on both its left and right banks, is flanked by areas underlain by marine Cretaceous rocks, where the depths from the surface to unweathered sediments are of the order of one to seven feet.

2.3. Tertiary to Recent.- The largest occurrence of red sandstones, which are considered to be the oldest member of the Tertiary sediments present in the area, forms a belt to~~f~~ the west of and parallel to the Pongola River, between Mlambangwenya and Ndumu, although separated from the river by a zone underlain almost entirely by marine Cretaceous sediments (See folder 1). The greater part of the coastal plain to the east of the Pongola is underlain by Tertiary sediments consisting chiefly of white sand, which in turn overlies marine Cretaceous sediments. Along its western margin, the Tertiary cover of sand is only a few feet thick, but this increases in an easterly direction. It should be noted, however, that from its emergence from Pongola Poort to as far north as Tete Pan, a distance of some 25 miles, the right bank of the Pongola is flanked by marine Cretaceous rocks. River terrace gravels and alluvium are found along the Pongola River in discontinuous stretches, and also along most of the streams draining from the Lebombo Range into the Pongola.

3. Surface Water

The most prominent feature on the Makatini Flats is the Pongola River itself, whose flow varies from a few hundred cusecs in the winter and early spring months to more than 20,000 cusecs during the peak rainfall months. The Ingwavuma River, an important tributary of the Pongola, joins the latter near its junction with the Usutu River. Many minor streams draining the Lebombo Range to the west join the Pongola River on its left bank on the Makatini Flats.

Many water samples taken from the Pongola River and its tributaries during the past few years have been analysed. The results of a few analyses are listed in Table 2, and the sites from which the samples were collected are shown on Folder 1.

The numerous pans occurring along the Pongola between Jozini and Ndumu from a very prominent feature in the area. I~~t~~n times of flood, the Pongola overflows its banks and drains into the riparian depressions to form extensive bodies of water locally known as pans. When the floods recede, some of the water stored in the pans returns to the Pongola and drains out of the area, but the pans retain sufficient water to remain as permanent water bodies throughout the year.

A large number of water samples collected from permanent pans in the area has been collected and analysed. The results of the analysis are included in Table 2. These indicate that at the time when the samples were taken, the quality of the water was very good, with the exception of Tete Pan, whose total dissolved salts amounted to 3627 ppm.

4. Geohydrology

Some salient features in connection with the quality of the groundwater occurring in the Cretaceous and Tertiary sediments underlying the Makatini Flats are given below.

4.1. Groundwater in the Cretaceous sediments

4.1.1. Published Information.- It has been known for a long time that the groundwater occurring in the Cretaceous sediments in other parts of the Republic, as for instance in the Worcester, Mosselbay, Gamtoos, Uitenhage, Oudtshoorn and Alexandria areas in the Cape Province, is highly saline in character and averages about 3500 parts per million total dissolved solids, which, with the exception of only one waterbearing formation, is the highest in the Republic. (Bond, 1947, p. 165). This also applies to the Cretaceous sediments underlying the Makatini Flats in the area under consideration. Van Wyk (1963, p.101) states that the groundwater in the Cretaceous beds on the Zululand coast usually contain more than 3,500 ppm of dissolved salts. Van Wyk found great difficulty in obtaining samples of groundwater from the Cretaceous sediments, since relatively little drilling for water had been carried out in it and most bore-holes were abandoned soon after they had been sunk on account of the high salinity. This explains the paucity of detailed chemical data on the groundwater in the area and the difficulties encountered during the present visit in obtaining additional information covering the whole area.

4.1.2. Information provided by bore-holes.- During 1966, six bore-hole sites were selected by the Geological Survey in the southern part of the area for the purpose of supplying water to displaced cattle from the drought-stricken areas of northern Transvaal. Of the six sites selected, only four were drilled by the Department of Water Affairs. Three of these, Nos. G. $\overset{2}{3}$1428 - 30, occur on Tertiary to Recent sands near the Ophanzi Pan, while the remaining bore-hole, No. G 21432, was sited near the contact between the dacite and the lower Cretaceous sediments near the Pongola River east of Jozini. A negligible amount of water was found in G. 21432, which was consequently abandoned. In G. 21428 - 30, near the Ophanzi Pan, water was found at depths varying from 5 to 8 feet. These three holes were started in Tertiary and Recent sands which were penetrated at shallow depths, when the drilling was continued into the underlying marine Upper Cretaceous sediments. G. 21430 reached a maximum depth of 215 feet into the Cretaceous sediments. The three bore-holes yield water varying from 300 to 800 gph.

One bore-hole is known to occur in Lower Cretaceous sediments at an old N.R.C. camp in the Ndumu Game Reserve, a few miles to the north-west of the Ndumu farms. In August, 1967, an experimental bore-hole was drilled on Ndumu A, with the primary object of obtaining a sample of groundwater from the Upper Cretaceous sediments occurring in this area. This bore-hole reached a depth of 249 ft., and when the water sample was taken in November, 1967, the water level stood at 241 ft. below surface. No other bore-holes are known to occur in the area.

Extracts from the chemical analyses of the waters from bore-holes G. 21428 - 30, from the old N.R.C. camp in the Ndumu Game Reserve (J.W.P. 633) and of the experimental bore-hole on Ndumu A (JWP. 696) are given in Table 3. The exact localities of the samples are shown on Folder 1. For easy reference, the percentage composition based on the mean of 77 analyses of ocean waters from many localities (Clarke, 1924, p.127) is included in Table 3, with the actual average concentration of the various constituents computed on a basis of 35,000 parts per million total dissolved solids.

The chemical analyses constitute clear evidence that the groundwaters harboured in the Cretaceous sediments are highly mineralized, thus confirming the observations made by Bond (op. cit., p. 165) and Van Wyk (op. cit., p. 101).

It has already been pointed out that the Upper Cretaceous sediments on the Makatini Flats are of marine origin. The groundwater harboured in them should, therefore, possess an oceanic character with $Cl > SO_4 > CO_3$ and $Na > Mg > Ca$, similar to the analysis of sea water quoted in Table 3. The analyses of the three groundwaters in Table 3 confirm this, except that the values for calcium are in excess of those for magnesium. It is possible, however, that this was brought about during diagenesis, when the groundwater remained in prolonged contact with limestone, which is a common constituent of the Cretaceous sequence. The conclusion is therefore reached that these groundwaters originally possessed a true oceanic character.

The Upper Cretaceous sediments form a continious belt from south to north on the Makatini Flats, and there is no doubt that the groundwater occurring in them are mineralized throughout. The analysis of the groundwater sample from the Lower Cretaceous sediments near Ndumu in the north also indicates an appreciable salinity which, however, is much lower than that of the overlying exclusively marine sediments. The principal conclusion that can be drawn from this is that the Cretaceous rocks underlying the Makatini Flats constitute a large reservoir of saline sediments and that irrigation water coming in contact with them will dissolve and remove soluble salts if allowed to pass over or through them.

4.1.3. Information provided by recent soil surveys.- Soil surveys by the Department of Agricultural Technical Services have shown that on both the left and right banks of the Pongola River there are low-lying areas underlain by Cretaceous sediments, (or occurring below or near areas where Cretaceous sediments are found at depths of one to three feet below surface), which by analyses have proved to be saline.

4.1.4. Information provided by Inyameti Pan, Ndumu Game Reserve.- The run-off which empties into this pan is derived chiefly from the northern parts of the farms Ndumu A and Ndumu, where soils with a high saline content overlying Cretaceous sediments are known to exist. The Inyameti Pan empties into the Pongola River, but when the latter is in flood, quantities of flood water with total dissolved salts of less than 100 ppm., discharge into the pan. During periods of low flow, a proportion of the water in the pan once more returns to the Pongola. The water in the pan is therefore derived from two sources, namely from surface run-off pan and from the Pongola during times of high flood.

One sample of water, JWP. 626 (W. 514), was taken at the outlet of the pan on 13th May, 1967, when there was a discharge of water from the pan into the Pongola at a rate of some 10 cusecs. Another sample, JWP. 627 (W. 515), was collected on the same day from the upper (western) end of the pan, where surface run-off from the west and from the Ndumu farms, enters it. The results of the analyses of these two samples, together with the results of the analyses of two samples of floodwater from the Pongola are given in Table 4. The exact localities of the two samples taken from the Inyameti are shown on Folder 1.

Table 4.- Chemical analyses of water from Inyameti Pan and Pongola River.

TSK 19/9/79

Lab. No.	Inyameti Pan Water		Pongola Flood Water	
	W514/67	W515/67	W518/67	W520/67
No. of Water Sample (Geol. Survey)	outlet JWP.626	W-end JWP.627	– (Flow 14000 cusecs)	– (Flow 20000 cusecs)
Dionic Conductivity (Micromhos @ 200)	2,700	16,000	60	80
	Parts per million			
Total Dissolved Solids	1,657	11,290	30	43
Na	409	2,645	5	6
Ca	80	468	4	8
Mg	96	761	2	3
Cl	852	6,110	7	7
SO_4	134	1,153	Nil	Nil
HCO_3	171	305	24	37
	Percentage Composition			
Na	23.5	23.1	11.9	9.9
Ca	4.6	4.1.	9.5	13.1
Mg	5.5	6.6	4.8	4.9
Cl	48.9	53.4	16.7	11.5
SO_4	7.7	10.0	Nil	Nil
HCO_3	9.8	2.7	57.1	60.7

The analyses in Table 4 show clearly that the water in the Inyameti Pan is highly mineralized, despite dilution by floodwater from the Pongola, which is of great chemical purity. Within the pan itself, there is a great variation in the concentration of dissolved solids. For example, at the inlet of the pan in the west, the concentration of salts was 6.8 times greater than at the outlet. This must be due to ineffective mingling of the water draining into the pan with the floodwater entering it from the Pongola.

There is a striking difference in the percentage composition of the water stored in the Inyameti Pan and of that of the Pongola floodwater. In view of this, there can be no doubt that the salinity occurring in the pan water could not have been derived from the Pongola floodwater through concentration. Therefore, the only alternative source of the salt must be the Cretaceous sediments to the west which underlie the catchment draining into the pan.

A strong resemblance between the percentage composition of the water in the pan and the groundwater derived from bore-holes G. 21428 - 30 in the marine Cretaceous sediments in the south of the area is revealed by a comparison of Tables 3 and 4. This affords additional evidence that the salts in the pan are derived from the Cretaceous sediments to the west.

4.2. Groundwater in the Tertiary and Recent Sediments.-

It is known that the groundwater occurring in the Tertiary and Recent sediments lying to the east of the Cretaceous rocks in the area under consideration is not highly mineralized and that the total salinity averages less than 600 ppm (Van Wyk, op. cit., p. 104, 107, 108).

As already pointed out above, the Tertiary sands which harbour groundwater of good quality, overlie Cretaceous sediments which yield highly mineralised groundwater. Over most of the coastal areas, therefore, groundwater of good quality overlies groundwater of a high salinity. This is illustrated by the water quality map of Van Wyk (op. cit., p. 102).

5. The Problems of Salinization and Waterlogging

5.1. Salinization in other areas.

Before considering the possibility of waterlogging and the problem of salinisation of return seepage on the proposed irrigation scheme on the Makatini Flats, it would be well to look at the results obtained at three existing irrigation schemes in the Republic, where the extent of waterlogging and salinization has been established empirically.

5.1.1. The Pongola Irrigation Scheme.- This area is located some 45 miles upstream from Pongola Poort and is underlain by sandstones and shales of the Ecca Series, which were deposited in a fresh water, lacustrine and/or estuarine environment. These sediments have been intruded by a series of dolerite sills and dykes.

The results of analyses of groundwater samples from five boreholes drilled into these sediments, are given in Table 5, which also gives the analyses of the irrigation waters used on the settlement, as well as the analyses of water from three local streams and of 11 seepage samples collected from seepage drains in the irrigated area. The sites from which these samples were taken are shown on Folder 2, except for samples W144/64 and W2015/63, whose exact localities could not be identified.

The principal conclusion that can be drawn from Table 5 is that whereas the irrigation water utilised on the Pongola Irrigation Settlement is of excellent quality chemically and that the groundwater occurring in the sediments underlying the irrigated area is also of good quality, the seepage water obtained from drainage ditches has deteriorated considerably in the course of its passage through the irrigated soils. It is not feasible from the analytical details in Table 5 to calculate the average composition of the return seepage from the settlement scheme as a whole, but it is clear that the increase in the salinity of the seepage ranged from two to more than 20 times the composition of the bore-hole waters, when, however, the composition of the seepage waters is compared with the raw irrigation water taken at the diversion weir and from the canal in Pongola, it will be seen that the ratio of salinization ranged from about five to more than 50.

5.1.2. <u>The Gam~~b~~toos Valley Irrigation Scheme</u>.- This irrigation scheme is located in the lower parts of the Gamtoos River in Cape Province and extends from Kwagga in the north-west, to Patensie, Hankey and the Loeries River in the south-east. The irrigation area is underlain by Lower Cretaceous sediments consisting of white and reddish conglomerates, light-coloured sandstones, reddish mar~~b~~l and grey sandy clays, similar to the Lower Cretaceous beds occurring between the Lebombo Range and the Pongola River in the Makatini area. It is of interest to note, however, that within the Gamtoos River valley, "no deposits attributable to the Marine beds stage have been discovered". (Haughton et al., 1937, p. 27).

An extensive search for representative analyses of groundwater occurring in the Lower Cretaceous sediments in the Gamtoos valley was made, but little useful information was found. The reason for this seems to be that the water found in bore-holes drilled into these sediments generally proved to be brack (Haughton, op. cit., p. 48), and the need to analyse consequently did not arise. Bond (op. cit., p. 165) also referred to the difficulty experienced in finding groundwater samples for analyses from the Cretaceous sediments, again for the reason that few bore-holes have been sunk into these rocks and that, because of the high salt content of the water, many bore-holes were no longer in use. Bond's statement that groundwaters occurring in the Cretaceous sediments in Cape Province averaged about 3500 ppm of total dessolved solids, has already been quoted (op. cit., p. 163). The only unpublished analyses which came to hand are of bore-hole waters from the farms Buffelshoek and Mondplaas, which varied from 1610 ppm (Buffelshoek) to as much as 36,000 ppm (Mondplaas), but as these localities are situated in the lower-most part of the valley, they cannot be taken as typical or representative.

Rosenstrauch and Bouwer (1958) and Murray (1961) have furnished useful information about the problem of salinization in the Gamtoos Valley. They have presented analyses of raw river water as well as of return seepages from the irrigated areas. The relevant details have been extracted from their reports and are given in Table 6.

A study of Table 6 shows that the seepage waters derived from the irrigated lands in the Gamtoos Valley have picked up large quantities of salts in these passage# through the soil. A comparison of the seepage and irrigation waters shows that the saline content of the former was from fi~~n~~ve to more than 10 times greater th~~o~~an that of the irrigation water derived from the Gamtoos River and its tributary the Klein River.

5.1.3. <u>The Vaal-Hartz Irrigation Scheme</u>.- Salinization and waterlogging at this scheme, which is is located on the Hartz River between Vryburg and Kimberley and utilises irrigation water from the Vaal River, have recently been studied by Temperley (1967).

The irrigation area is underlain by impermeable Dwyka shale and tillite, which are overlain by a comparatively permeable zone consisting of aeolian Kalahari sands, alluvial sand, gravels and calcrete.

Waterlogging and salinization are common hazards in the Vaal-Hartz Irrigation area and Temperley (op. at.) found that the basic cause of these phenomena is the virtual absence of natural drainage, which is due to the general impermeable nature of the zone overlying the bedrock.

5.2. Factors affecting salinization and waterlogging on the Makatini Flats.- Deterioration of the productive capacity of irrigated soils may be brought about in the following manner -

1. Salinization due to concentration and accumulation in the soil profile of salts harmful to plant growth.
2. Waterlogging conditions, involving an excess of moisture in the soil profile due to lack of natural drainage.

The possibility of salinization and waterlogging of soils on the Makatini Flats will depend on the saline content of the sediments through which the irrigation water will pass, the physical condition of the irrigated soils, the chemical composition of the irrigation water and the effects of evapotranspiration in the irrigated areas. These parameters are further discussed below.

5.2.1. The saline content of the sediments underlying the irrigation area.- It has been proved beyond doubt that the Upper Cretaceous sediments underlying the Makatini Flats are of marine origin and contain large amounts of connate salts, that is, salts which were originally present in the sea in which these sediments were laid down and which became entrapped in the interstices of the sediments at the time of deposition. The saline content of the sediments

Table 6.- Chemical analyses of River Water and Seepage Water in the Gamtoos Valley.

Lab. No.	Irrigation Waters			Seepage Waters				
	W192/57	W907/60	W918/60	W191/57	W912/60	W913/60	W916/60	W917/60
Source	Rademeyer Dam	Gamtoos River	Klein River	Seepage Kwagga-Patensie	Seepage Patensie. Mr Ferreira	Seepage Hankey pool TG.51-52	Seepage Hankey pool TG. 34	Seepage Hankey Mr.Clue
Dionic Conductivity	440	300	340	1850	2200	4350	6025	600
	Parts per million							
Total dissolved Solids	284	194	219	1193	1419	2800	3886	3871
Na.	61	40	52	367	316	143	766	934
Ca.	18	12	28	24	74	128	261	160
Mg.	12	9	9	41	71	250	243	19~~8~~5
Cl.	92	69	66	398	540	1661	1882	1917
SO_4	19	Nil	10	125	120	10	288	154
HCO_3.	95	67	140	326	317	842	445	445

Analyses by Soils Research Institute, Pretoria.

is reflected in the high salinity of the groundwaters occurring in these deposits, vide the chemical analyses in Table 3. Soil surveys carried out by the Dept. of Agricultural Technical Services have also revealed the occurrence of saline soil areas in many places on the Makatini Flats.

A study of the geological map accompanying this report will show that the marine Cretaceous sediments underlie both the right and left banks of the Pongola River below the J.G. Strydom Dam. Any irrigation seepage leaving the irrigated lands must therefore pass over or seep through these marine sediments before draining away into the Pongola River. In its passage through and across the Cretaceous sediments and the highly saline soil areas associated with these sediments, especially those occurring in the low-lying parts, any seepage water or runoff will dissolve soluble salts encountered en route and transport them to the Pongola if the necessary hydraulic gradient exists. If, however, drainage is impeded by adverse slopes or by impermeable soil conditions, excess water will accumulate in the soil profile, giving rise to waterlogging conditions.

5.2.2. The physical condition of the irrigated soils.- The soils occurring on the Makatini Flats have been studied in detail by the Dept. of Agricultural Technical Services and the principal soil types have been identified and classified (Hensley, 1948). In this work, special attention was given to the physical and chemical properties of the soils and the distribution of the soil types in the area under consideration. The principal basis of classification was the suitability of the soils for irrigation with the type of water to be supplied by the J.G. Strydom Dam.

A summary of the principal soil groups and of the associated soil types on the Makatini Flats is given in Table 7.

Table 7.- Soil groups and soil types occurring on the Makatini Flats (After Hensley, op. at.)

Group	Name	Type No.	Description
A	Alluvial Soils	1	Coarse and medium-textured alluvial soils.
		2	Fine-textured alluvial soils.
B	Residual (or Terrace) Soils	3	Dark red-brown to dark-brown sandy clay to clay.
		4	Red to red-brown sandy loam to clay.
		5	Dark-brown to black clay.
C	Deep, sandy Soils	6	Light-brown to grey-brown sand (white sand).
		7	Yellowish sand to loamy sand.
		8	Red to red-brown sand to loamy sand
D	Sandy soils on a cemented layer	9	Sand to loamy sand on a cemented layer, less than 3" deep.
		10	Sand to loamy sand on a cemented layer 3 ft. to 6 ft. deep.

As will be seen from Table 7, a cemented zone occurs in the Group D soils, which are derived from Tertiary and has a thickness ranging from one to two feet sediments and cover extensive areas in the southern and eastern parts of the area. The cemented zone occurs at depths varying between 6 inches to 8 feet. This zone has a low permeability and is characterized by a predominance of sodium over calcium and magnesium, which caused a dispersion (deflocculation) of the soil colloids, resulting in the formation of a dense and impermeable subsoil layer. In some places, as for instance on the left bank of the Pongola River between the farms Maarschalk and Lakeview, flocculation of ferri-oxides has given rise to incipient lateritization which similarly formed a relatively impermeable horizon in the soil profile. Then there are the Group B soils which overlie a thick succession of clayey Cretaceous sediments of low permeability. Because of their relatively high clay content, these soils have a limited permeability but the Cretaceous sediments underlying them are likely to be even more impermeable.

It is certain that the zones of low permeability referred to will impede drainage of irrigation water and unless remedial measures are taken, will ultimately give rise to waterlogging conditions in the areas where they occur. Unfortunately, the distribution and exact physical properties of these zones have not yet been accurately determined. A seismic hammer technique has been employed to ascertain whether the presence and depths of these zones can be determined instrumentally, but the results of the experiments have not been conclusive. Further experimentation in this field is warranted.

5.2.3. The composition of the irrigation water.- Analyses made of floodwater from the Pongola River show that the content of total dissolved solids can be as low as 30 p.p.m. (See Table 4). Reference to the percentage composition of the floodwaters indicates that Na^+ is the dominant cation, while HCO_3' and Cl' are the principal anions. Of the latter, HCO_3' ranks as the major anionic constituent, amounting to nearly 60 per cent of total composition. This, however, must be regarded as normal for water derived from a continental provenance.

Analyses of the water from the numerous pans occurring on the flood-plain of the Pongola on the Makatini Flats show concentrations of total dissolved solids ranging from 61 to 362~~2~~7 p.p.m. (See Table 2).

The theoretical composition of the irrigation water that will eventually be stored in the J.G. Strydom Dam has been computed statistically[+] and is given in Table 8.

Table 8.- Computed composition of irrigation water in J.G. Strydom Dam.

	p.p.m.	M. eq/1
Na	40.3	1.7
Ca	12.9	0.7
Mq	12.2	1.0
		3.4
HCO_3	104.2	1.7
$Cl(+SO_4)$	59.5	1.7
		3.4
Total dissolved solids	229.1	

According to the standards laid down by Wilcox (1948) and the U.S. Salinity Laboratory (1954), the stored water possesses a S.A.R. of approximately 2 and falls in the C_2S_1 class of irrigation waters. This suggests that the raw water will be suitable for irrigation, but it must be noted, however, that the bulk of the cationic constituents is represented by sodium, while the major anionic compounds consist of HCO_3.

[+] Hensley, M. - Personal communication.

5.2.4. The effects of evapotranspiration.- It is a well-known fact that in places where the water table lies at ground surface, or only a few feet below it, or in cases where the soil profile has become saturated with irrigation water, large amounts of moisture may be returned to the atmosphere as a result of direct evaporation. This must inevitably result in a concentration of the salts present in the soil moisture, a process which in some instances may cause a proportion of the saline matter to be deposited on the surface. This is particularly noticeable in areas where sub-surface drainage is impeded or obstructed by the presence of a zone of low permeability in the soil profile.

An increase in salinity may also be brought about by transpiration of vegetation, as a result of which moisture is abstracted from the soil or from the water table. It is known that roots of certain plants are capable of penetrating to depths of 80 feet or more and that transpiration by the indigenous vegetation between Hluhluwe and Mkuze in Zululand is responsible for enormous losses of groundwater (Van Wyk, 1963). Van Wyk (op. at.) put forward evidence to prove that the recharge of the water table in these areas only takes place where there is a concentration of rainfall and cited his rather surprising finding that during the period between 1943 to 1956, little, if any, recharge of the water table occurred, despite the fact that the rainfall during this period was practically normal, and in the case of five years actually higher than the 29-year average for the area. He ascribed this astonishing feature to the probability that evapotranspiration was so active in the area that moisture which accumulated in the soil was dissipated and returned to the atmosphere. This process appears to have been so effective that the moisture content of the soil was kept well below field-capacity during the entire period, with the result that rainwater was unable to percolate downwards to the water table.

The effect of evapotranspiration on the behaviour of the water table under certain geological conditions is well illustrated in an area in False Bay, on the western shore of Lake St. Lucia, where a thin mantle of Tertiary sediments overlies a marine Cretaceous succession, similar to that occurring on the Makatini Flats. Here also, an impermable, cemented horizon, identical to that occurring on the Makatini Flats is found at depths of generally less than 15 feet in the Tertiary Sands, which, before the area was settled, supported a dense growth of indigenous vegetation.

Around about 1950, a number of wells up to 40 feet deep, was dug in the Tertiary sands (Van Wyk, op. at.). Most of these were dry at the time. However, during the pin~~a~~e-apple boom some years late~~d~~r, the indigenous vegetation was cleared, and the water table immediately began to rise to within a few feet of the surface during the first rainy season. All the shallow wells then yielded water all the year round and some of the area had to be drained in order to save the crops.

It is clear that before this area was denuded of bush, an equilibrium existed between rainfall and the moisture requirements of the indigenous vegetation, and that evapotranspiration equalled or exceeded the total amount of rainfall that infiltrated into the soil. When the indigenous vegetation was removed, moisture losses due to evapotranspiration were eliminated or reduced to such an extent that the rainwater could percolate to the impermeable zone, where it accumulated to form a perched water table, which eventually rose to the surface, causing waterlogging conditions. It is obvious that if the area had been irrigated, the process of waterlogging would have been accellerated.

The principle conclusion that may be drawn from this is that a similar train of events may be expected to develop in some parts of the

Makatini Flats where identical geological conditions exist. In areas where drainage is likely to be impeded by the existence of impermeable zones in the soil profile, removal of indigenous vegetation may give rise to the formation of perched water tables and waterlogging, merely as a result of normal rainfall. Application of surface water by means of irrigation is likely to accellerate and accentuate this process. On the other hand, in well-drained areas where no impermable zones are present, the removal of indigenous vegetation, followed by the application of irrigation water, is not likely to culminate in waterlogging conditions. It is therefore essential to investigate in detail the nature and distribution of the zones of low permeability over the whole area, before a decision is made on the best and most economical methods of drainage, such as by means of buried porous pipe systems or by open ditches.

5.3. Salinization of the Return Seepage.- The amount of return seepage from irrigation is generally considered to be of the order of one-tenth of the total quantity of water used on the irrigated lands. The total amount of water scheduled for both the right and left flanks of the Pongola River on the Makatini Flats is taken to be 2200 cusecs. The amount of seepage which will return to the Pongola is therefore estimated at about 220 cusecs.

There is no doubt that seepage water from the Makatini Irrigation Scheme will pick up considerable amounts of soluble salts on its return to the Pongola River, but as pointed out above, the degree of salinization will be determined by a variety of parameters, whose overall effect cannot be assessed in advance of the operation of the scheme. All that, therefore, remains in this report is to make an *estimate* of the extent of the salinization, by applying the empirical results obtained in other irrigation schemes in the Republic. By analogy, therefore, and provided the return seepage is not unduly diluted by raw irrigation water or by runoff derived from rainfall, salinization on the Makatini Flats may be expected to be of the following order;-

1. A minimum of twice the composition of the groundwater underlying the area, vide the analogy of the Pongola Irrigation Settlement.
2. A minimum of five times the composition of the raw irrigation water to be used, vide the analogy of the Pongola and Gamtoos Irrigation Settlement.

If the average composition of the groundwaters occurring in the marine Cretaceous sediments is taken to be 500 ppm., which is an extremely conservative assumption in view of the high salinities that these groundwaters prossess (see Table 3), then by application of the first empirical result, the return seepage may be expected to attain a salinity of the order of 1000 ppm. If, on the other hand, the average composition of the raw irrigation water is taken to be 250 ppm., which is the approximate salinity calculated for the stored water in the J.G. Strydom Dam, (see table 8), then the extent of the salinization of the return seepage may be expected to be of the order of 1100 ppm, which is obtained by application of the second empirical result mentioned above. Here again the salinization factor employed is a most conservative one and in view of the empirical results referred to, the figure obtained must be lokked upon purely as a minimum.

6. Summary and Conclusions

6.1. A brief description is given of the geology of the Makatini

Flats in this paper. The Flats are underlain by Cretaceous sediments consisting of clayey sandstone, sandy shale and limestone. Tertiary sandstones overlie the Cretaceous beds in the eastern part of the area, as well as in an elongated area to the west of the Pongola River. Rhyolites and dacites of the Stormberg Series occur to the west of the area under consideration.

6.2. Details are given of surface water in the area, especially the occurrence of permanent pans along the banks of the Pongola River. Chemical analyses indicate that the quality of these waters was very good, with the exception of Tete Pan, whose total dissolved salts amounted to 3627 ppm.

6.3. The occurrence of groundwater in the Cretaceous rocks is described and it is pointed out that groundwater derived from these sediments invariably are highly saline, with total dissolved salts in excess of 1600 ppm. It is also shown that the salts occurring in these sediments are marine in origin and that the groundwaters have an oceanic character.

6.4. Groundwater occurring in the Tertiary and Recent sediments are generally of good quality.

6.5. The problems of salinization and waterlogging in the soils on the Makatini Flats are briefly discussed and reference is made to the Pongola, Gamtoos and Vaal-Hartz Irrigatioh Schemes. A large volume of chemical data is presented to indicate the extent of salinization in the Pongola and Gamtoos areas. A comparison of the seepage and irrigation waters in these two areas showed that the salinization ration of the former ranged from a minimum of about five to a maximum of over 50, and that of the latter from five to more than 10. A comparison of the seepage and groundwaters in the Pongola Irrigation Scheme revealed a salinization ration ranging from two to more than 20.

6.6. The most important parameters that will influence salinization and waterlogging on the Makatini Flats are briefly discussed. They are the saline content of the sediments through which the irrigation waters will pass, the physical condition of the irrigated soils, the composition of the raw irrigation water and the effects of evapotranspiration in the irrigated areas.

6.7. There is no doubt whatever that in view of the saline character of the sediments which underlie the proposed irrigation area on the Makatini Flats, taken in conjunction with the other parameters conducive to salinization, the salinity of the seepage water from the Makatini Irrigation Scheme will be increased during its passage through the irrigated sediments and during its return to the Pongola River.

6.8. Application of the empirical results obtained in the Pongola and Gamtoos Valley Irrigation Schemes suggested that the composition of the return seepage from the proposed irrigation scheme on the Makatini Flats may be expected to be of the order of 1000 ppm. total dissolved solids. This is a purely hypothetical conclusion as the actual degree of salinization will depend on the interplay of a number of parameters. It may be stated, however, that in some instances, as for example in areas where well-drained soils occur, such as on the Lower Cretaceous and Tertiary sediments, the composition of the return seepage may be expected to fall within the range between 229 - 1000 ppm., while on those soils which directly overlie the Upper Cretaceous sediments, the return seepage may be expected to exceed 1000 ppm. in total dissolved solids.

6.9. The prediction may also be made that when the J.G. Strydom Dam is completed, the Pongola River will no longer overflow its banks and will accordingly cease to feed the numerous pans occurring on the

Makatini Flats, with the exception of pans like the Mzinyene and Mfongozi which are fed by seasonal streams dra~~w~~ining the Lebombo Range to the west of the proposed irrigation area. It would appear, therefore, that the salinity of the water stored in the pans will increase and that some of them will eventually dry up.

Pietermaritzburg,
11th September, 1967.

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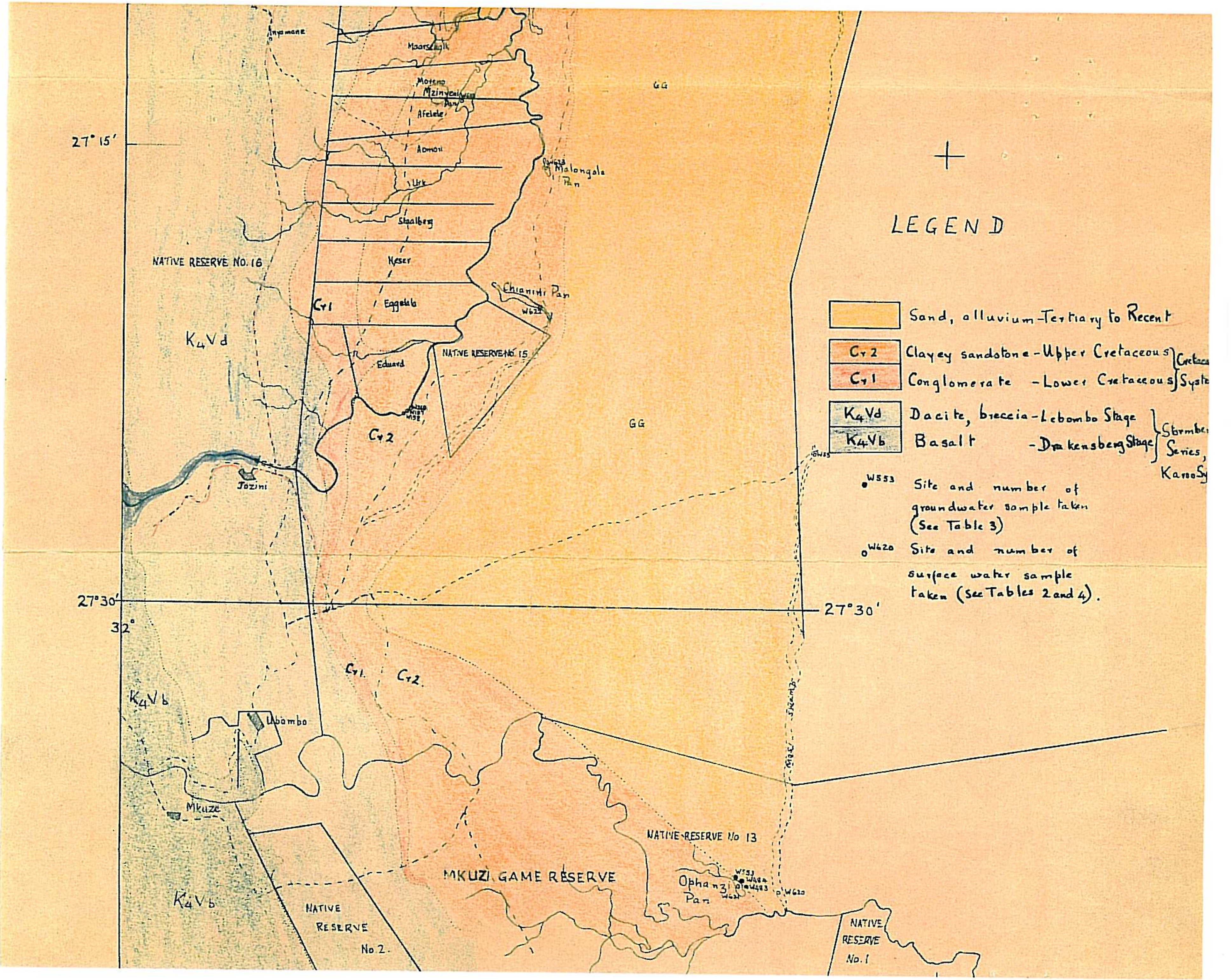
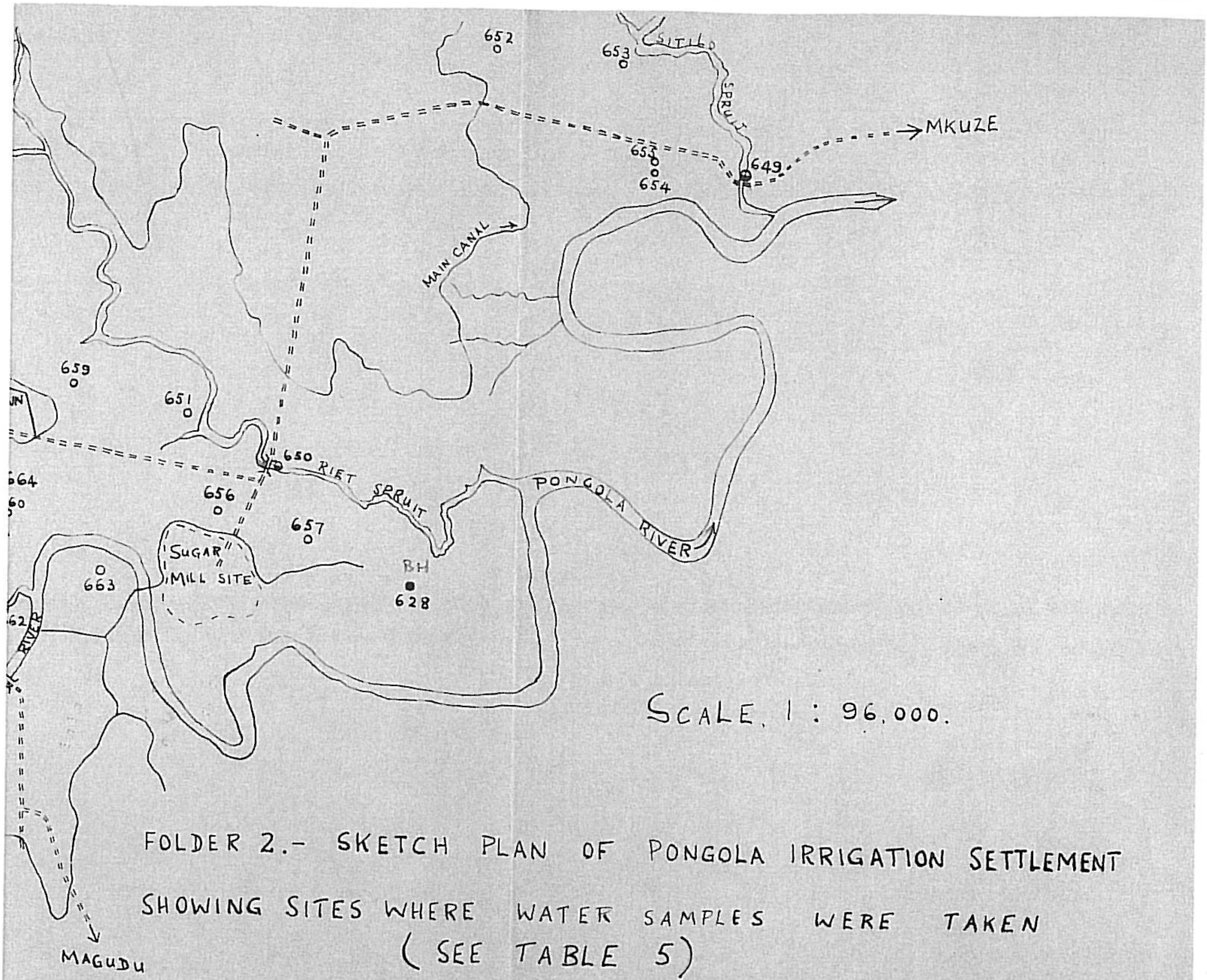
27° 15'
27°30'
32°
27°30'
LEGEND
Sand, alluvium-Tertiary to Recent
Cr 2 Clayey sandstone-Upper Cretaceous
Cr 1 Conglomerate -Lower Cretaceous
Cretac
Syste
K4Vd Dacite, breccia-Lebombo Stage
K4Vb Basalt -Drakensberg Stage
Stormbe
Series,
KarooSy
W553 Site and number of groundwater sample taken (See Table 3)
W620 Site and number of surface water sample taken (See Tables 2 and 4).
Inyamane
Maarschalk
Moteno
Mzinyeni Pan
Afelele
Aomon
Urk
Staalberg
Keser
Eggeleb
Eduard
W622
Malongale Pan
W623
Chianiti Pan
W621
NATIVE RESERVE NO. 16
NATIVE RESERVE NO 15
W158
W157
W158
GG
GG
GG
K4Vd
Cr 1
Cr 2
Jozini
Cr1
Cr2
K4Vb
Ubombo
Mkuze
K4Vb
NATIVE RESERVE No 2.
MKUZI GAME RESERVE
NATIVE RESERVE No 13
Ophanzi Pan
W553
W484
W483
W621
W620
NATIVE RESERVE No. 1



FOLDER 2.- SKETCH PLAN OF PONGOLA IRRIGATION SETTLEMENT SHOWING SITES WHERE WATER SAMPLES WERE TAKEN (SEE TABLE 5)

LEGEND

64 - Locality and number of irrigation water.

- Locality and number of stream water.

●628 - Locality and number of groundwater (boreholes)

651 ○ - Locality and number of seepage water.