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HYDROGEOLOGY AND GROUNDWATER DEVELOPMENT IN SWAZILAND

by

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Contents

ABSTRACT

Swaziland is bordered by Mocambique and South Africa. It has an area of 17 364 square kilometres and a mainly rural population of half a million. Urban and industrial water requirements are largely drawn from surface water supplies, but groundwater is increasingly being used to supply rural communities. There are four distinct topographic and climatic regions orientated north-south: the Highveld, mountainous and well watered; the Middleveld which forms a transition to; the Lowveld, which is generally flat-lying and receives only half the rainfall enjoyed by the Highveld; and the Lebombo, an escarpment with a climate slightly cooler than the Middleveld. Vegetation varies from the parkland with thorn scrub in the Lowveld to the short grasses of the Highveld.

Generally the older rocks occur in the west and the younger to the east. The Archean granitic rocks and the Ancient Gneiss Complex precede the Swaziland System, nowmetamorphosed to varying degrees. Intense deformation was associated with the intrusion of granites. Following a long period of erosion and peneplanation the Karroo System of sediments and younger lavas was laid down with later Karroo intrusives forming sills and dykes. The Lebombo Monocline gives rise to further erosion although Recent alluvial deposits are limited.

Few of the formations are water bearing. The Karroo sandstones are too fine-grained to transmit sufficient water for borehole abstraction. Features of secondary permeability such as joints and burned contacts adjacent to intrusives are the main sources of groundwater. Exceptions are the weathered crystalline rock aquifers of the Ezulwini Valley and Malkerns. Groundwater is usually confined, but the average borehole pumping yield is only 0.9 l/s.

Pure slightly acid water occurs in the Highveld granites and granite gneisses. Total dissolved solids are higher in the Middleveld granites where calcium bicarbonate type water occurs with concentrations greater than 1 000 mg/l. The Karroo has generally higher concentrations although the rhyolites are relatively fresh.

Ten thermal springs are known along two regional trend lines. Discharge temperatures vary between 33 and 52°C and the maximum discharge is 10 l/s. The water is meteoric in origin and has been heated at depth.

Borehole site selection often depends on the location of dyke and joint systems. Photogeology and field surveys including geological and geophysical methods are used, although the success of the electrical resistivity method is limited. Records of all new Government drilled wells are kept and some also from the private sector. Attempts to assess water balance and recharge are being made from long term water level and chemical observations.

It is recommended that Government should let all its water-borehole drilling work to contract. Geological Survey should maintain the borehole records and location maps with the assistance of new legislation regarding the submission of data. Site selection and exploration work as well as some production drilling should continue. The Water and Sewerage Board should be primarily concerned with production drilling particularly for rural communities, and should be encouraged to make full use of the services provided by the Geological Survey Department. The Public Works Department should relinquish all claims to groundwater development work.

1. INTRODUCTION

Interest in groundwater within the Kingdom of Swaziland has only developed recently. By comparison to other sub-tropical countries, Swaziland is relatively well-watered and the numerous rivers and springs have been able to provide adequate supplies for domestic, agricultural and industrial purposes. In recent years attention has been given to groundwater with a view towards improving domestic water supplies to the many, and widespread rural communities.

Knowledge of the occurrence of underground water within the Kingdom is limited. Potential aquifers are now being identified but it will be some years before a proper understanding of the groundwater systems can be evaluated. This report does not pretend to be a definitive statement on the groundwater resources. Rather it is a collation of data that is available to date.

The Kingdom of Swaziland has an area of 17 364 square kilometres. It is about the size of Wales, a little over half the size of Lesotho and only 1/33rd the area of Botswana. Present day population is of the order of 500,000 (although initial figures from the 1977 census indicate it may be greater than 600,000). An estimated 5% of the population live in the two major towns, Mbabane the capital, and Manzini (Anon. 1976).

2. GEOGRAPHY

2.1 Location

Swaziland is situated in south-eastern Africa between the Natal and Transvaal provinces of the Republic of South Africa and the Peoples Republic of Mocambique. It is compact in shape and lies between latitudes 25° 43' S and 27° 18' S and longitudes 30° 47' E and 32° o8' E. The eastern boundary with Mocambique is in parts only 80 km from the Indian Ocean.

2.2 Topography and Drainage

The country is divided into four distinct regions extending longitudinally north-south (Figure 1). These are the Highveld in the west, the Middleveld, the Lowveld, and the Lebombo Escarpment in the east. They vary in width from 8 to 50 km but the Lebombo is never wider than 20 km. The area and average elevation of these regions is given in Table 1.

TABLE 1

	Area (km^2)	Average Elevation (m above mean sea level)
Highveld	5,030	1,300
Middleveld	4,597	700
Lowveld	6,416	200
Lebombo	1,321	600
Swaziland	17,364	700

The Highveld is an extension of the Drakensberg range and forms a wide belt of rugged mountainous terrain. The steep sided valleys gradually widen to the east to form the Middleveld with a more gentle topography. This in turn gives way to the Lowveld of even milder topography but with occasional kopjes and ridges rising above the general level of the plain. The Lebombo Escarpment rises along the eastern border and is breached only by the rivers Ngwavuma, Usutu (Lusutfu) and Mbuluzi within the borders of Swaziland. There are five river systems all generally flowing eastward towards Mocambique. From north to south they are the Lomati, Komati, Mbuluzi, Usutu and Ngwavuma. The river courses are incised and flood plains are virtually non-existent. With the exception of the Mbuluzi and Ngwavuma Rivers, the major water courses rise west of the border in the Transvaal Province of

South Africa. Water quality is generally good apart from the presence of bilharzia particularly in the lower lying regions. There are twenty three automatic gauging stations with more planned, largely to determine cross border flows (Latham 1976).

2.3 Climate

Swaziland lies in the fringe of the south-eastern trade wind belt. This provides a distinct wet season, particularly marked on the higher ground. The four topographical units provide regional differences in climate, with the higher land wetter in the summer and cooler in the winter. The Highveld receives rain either from sudden thunderstorms or from mist which may settle for several days at a time. 75 to 80% of the rainfall occurs in the summer months October to March (Table 2).

TABLE 2

Long-term Rainfall (mm)	Annual	Summer	Winter
Highveld	1,016 - 2,286	813 - 1,778	203 - 508
Middleveld	762 - 1,143	610 - 914	153 - 229
Lowveld	508 - 890	406 - 711	102 - 178
Lebombo	635 - 1,016	508 - 813	127 - 203

The rainfall in the Lowveld is characterised by heavy rainstorms with high run-off followed by long spells of hot dry weather. Mean monthly rainfall figures are given for selected stations in Table 3, and the rainfall distribution is shown in Figure 2.

The mean annual temperature in the Highveld is just over 15°C and in the Lowveld 22°C. Seasonally, Highveld temperatures range from 30°C to -1°C and the Lowveld from 44°C to 5°C, and the diurnal range, especially in the Highveld can be even greater. The Highveld commonly experiences frost in June and July and snowfalls have occurred on the mountains. Snow is also once recorded to have fallen in Mbabane. Parts of the Middleveld and the valleys of the Lowveld may also experience frost. Annual open water evaporation is thought to be of the order 1,200-1,500mm (Visser 1956).

TABLE 3

AVERAGE MONTHLY RAINFALL FOR SELECTED STATIONS - 1975 (mm)

Station	Long-term monthly average											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
HIGHVELD												
Havelock	288	266	195	103	44	27	25	38	81	159	212	259
Mbabane	245	211	175	77	34	19	21	28	62	129	178	214
Hlatsikhulu	183	157	123	69	30	17	18	24	58	115	165	179
MIDDLEVELD												
Matsapa	158	128	109	59	25	15	14	19	44	80	119	132
Khubutha	119	115	96	55	20	15	15	17	39	68	111	121
Nhlangano	127	122	85	66	25	15	14	18	47	83	130	130
LOWVELD												
Homestead	119	109	81	42	20	13	13	12	80	55	93	97
Big Bend	94	75	61	37	23	13	10	11	29	47	76	89
Lavumisa	80	82	55	41	21	13	11	15	31	52	79	84
LEBOMBO												
Siteki	138	131	111	59	29	17	17	19	42	76	103	122

After Anon 1976 Table B7 based on information supplied by the Ministry of Works, Power and Communications. Station localities are shown in Figure 1. Observation periods up to 54 years.

The intermediate climate of the Middleveld is similar to that of the Lebombo Escarpment, though the latter with its more open situation provides a cooler climate.

2.4 Vegetation

The natural vegetation in the Kingdom varies according to the climate. In the Lowveld there are dense thorny thickets but also more open parkland. The parkland contains fairly large trees 50 to 100m apart and a floor of sweet grass of high feeding value. This gives way to the tall grasses characteristic of the Middleveld though thorns and occasional trees persist. In the Highveld the grass is generally short and the valleys support a large variety of indigenous trees including the hardwood Mvangati, a species of Pterocarpus. The common species of vegetation that occur includes cycads, aloes, ferns, lilies and numerous varieties of wild flowers and flowering shrubs. Throughout the country the vegetation is subject to late winter bush fires producing a fire-ravished ecology.

The influence of man on the vegetation is marked. Large forestry concerns have been established in the Highveld. Mixed farming predominates in the Middleveld, but agriculture in the Lowveld relies on supplemental irrigation from surface water supplies to produce various cash crops. The Lebombo is least affected where cattle predominate.

3. GEOLOGY

The stratigraphy of Swaziland is given in Table 4, after Hunter (1961) and Figure 3 shows the geology.

3.1 Pre-Karroo

The Ancient Gneiss Complex forms a broad zone passing south-west to north-east through the centre of the country, with additional exposures in the north and around Mbabane. The Archean Swaziland System occurs along the north-western border of the Kingdom, and metamorphosed representatives of it occur more centrally. It is composed of lavas, intercalated sediments, and quartzites of varying degrees of metamorphism. In central Swaziland its metamorphosed equivalent is schists and crystalline "Basement" type rocks of variable mineralogy.

The granites and intrusives underlie about two thirds of the Kingdom. The composition ranges from dioritic to leuco-granitic, and there are several ages of granite formation listed in Table 4. The granites are directly or indirectly responsible for most of the mineral wealth of the Highveld and Middleveld.

The volcanics of the Insuzi Series occur in two roughly north-south oriented bands in the south of the country. The andesites are often considerably altered. Minor sediments occur within the volcanics but there are no tuffs or pyroclastic layers. The western outcrop thins towards the north. The eastern outcrop contains lenticular shaped sediments forming quartzites with intercallations of phyllite; it dips at 50 to 60° to the east.

The Mozaan Series comprises a series of quartzite and shale bands with one central tuff layer and a dark amygdaloidal lava at the top. Total thickness is between 3,000 and 4,000m and metamorphism is virtually absent.

The Post-Mozaan Usushwana Complex is a suite of rocks ranging from pyroxenite to granophyre occurring 15km south-west of Mbabane and shaped in a 'U' with the western limb across the border in South Africa. Its resistance to weathering produces high mountainous terrain.

Pre-Karroo intrusives comprise sills of gabbro-microgranite, diabase dykes and sheets, and quartz veining.

TABLE 4

SWAZILAND STRATIGRAPHY

TERTIARY TO RECENT		Alluvium, ferricrete
KARROO SYSTEM	Stormberg Series Beaufort Series Ecca Series Dwyka Series	Rhyolitic tuffs, rhyolite, basalt, sandstone. Grey shales and sandstone. Sandstones, coals, carbonaceous shales. Tillite and shale
	Unconformity	
PONGOLA SYSTEM	Mozaan Series Insuzi Series	Quartzite, ironstone, conglomerate. Andesitic and felsitic lavas, phyllites.
	Unconformity	
SWAZILAND SYSTEM	Moodies Series Fig Tree Series Onverwacht Series	Quartzite, conglomerate. Shales, cherts, jaspers. Acid and basic volcanics.
ANCIENT GNEISS COMPLEX		Grey biotite and hornblende gneiss, amphibolites and various gneisses representing ultra-metamorphism of the Swaziland System.
INTRUSIVE ROCKS	Post-Karroo Post-Archean Archean Post-Mozaan Archean Post-Swaziland System	Dolerites, microgranite and granophyre. Diabase dykes. Ag5 porphyritic granite. Gabbro, pyroxenite (Usushwana Complex). Ag3 medium grained grey granite. Migmatitic granite-gneiss. Granodiorite Suite.

3.2 Karroo and Recent

The Karroo System underlies the eastern Lowveld and the Lebombo Mountains. The general lithology is given in Table 5.

The Dwyka is comprised of tillites and shales. The tillite is dark green containing angular pebbles and boulders of granitic and quartzose material, with occasional varved clays. The outcrop is very limited and patchy.

The Ecca is more widely represented. It consists of a series of shales, sandstones, carbonaceous shales and coals, with a fine to medium grained, white, and homogeneous Basal Sandstone. The shales of the Lower Ecca are grey to black in colour and give way to a succession of felspathic and often cross bedded sandstones with grit bands. This gives way to a coarser sandstone with minor micaceous mudstone layers containing the eighteen coal bands of the coal zone. The Upper Middle Ecca and the Upper Ecca comprise a series of sandstones and carbonaceous shales and coals, and the sandstones are medium to coarse grained with occasional grits and shaley partings. The Beaufort Series of shales and shaley sandstones is only 40m thick and the outcrop is very limited in extent.

The Stormberg Series commences with the Molteno Beds, a series of fine-grained sandstones grading upwards into coarser gritty horizons with shale and one thin conglomerate. The Red Beds consist of red silt containing calcite nodules which straddles a minor sandstone layer. The Cave Sandstone is a fine-grained, even textured rock, which is light grey to yellow or green in colour. Towards the top of the Cave Sandstone, the basal tuffs of the Stormberg basalt are inter-layered with the sandstone. The basalt itself is characteristically hard and black, though its mineralogy and texture enable four different types to be identified. It forms a succession of great thickness and gives way to a thick and monotonous succession of welded tuffs and rhyolites that form the Lebombo Mountains in the east of the country. Geophysics suggest that the total thickness of the basalt is not less than 4,000m and that the Lebombo rhyolites and tuffs are between 6,500 and 8,000m in thickness (Burley et al 1970).

The Karroo intrusives comprise the sheets, sills and dykes of dolerite, and the microgranitic dykes and granophyre plutons that occur dominantly in the Karroo but also in older formations. Dyke swarms orientated along the

TABLE 5

STRATIGRAPHY OF THE KARROO SYSTEM

Series	Stage	Lithology	Thickness (m)
STORMBERG	Lebombo	Rhylotic tuffs, agglomerates and welded tuffs.	6,500 - 8,000
	Drakensberg	Basalt	at least 4,000
	Cave Sandstone	Fine to medium grained sandstone, greenish-grey in colour.	30
	Red Beds	Grey sandstones with calcite nodules.	40
	Molteno Beds	White quartzites, gritty sandstones and shales.	44
BEAUFORT		Grey arenaceous shales.	41
ECCA	Upper Ecca	Carbonaceous shales, shaley coals, coals and narrow sandstones.	163
	Middle Ecca	Sandstones, grits, narrow shales, coals and carbonaceous shales.	635
	Lower Ecca	Grey-black shales.	46
DWYKA		Tillites, shales, varved shales.	12
		TOTAL	at least 11,510

strike of the Karroo are common in the Lowveld. The dykes often weather to residual spherical boulders lying on a darker and redder soil than elsewhere.

Unconsolidated and partly consolidated material is confined mainly to the valleys, with limited alluvial flats along the major rivers. The alluvium is of variable age and ranges from one or two metres to a maximum of 30m thickness. Superficial deposits occur as a result of erosion and peneplanation and are generally of limited thickness.

4. HYDROGEOLOGY

Figure 4 shows the distribution of known water boreholes in Swaziland. The most densely drilled areas occur in the Ezulwini Valley south of Mbabane and to the south again in the Malkerns Farmlands. The towns of Manzini and Siteki have relied heavily on groundwater in the past though it is now largely superseded by reticulated surface water. All the other large townships depend on surface water supplies. The distribution of boreholes elsewhere reflects the development of the land which in turn reflects access to it and in the Lowveld the availability of surface water for irrigation.

Borehole design is traditional and almost standard regardless of the formations penetrated. It consists of a 150mm drilled well containing 150mm plain casing down to solid rock and cemented in to a depth of about 1m from the ground surface. Hardly any slotted casing or screen has been used and consequently borehole yields tend to be low because any shallow groundwater is generally excluded from the borehole. In many cases it is these shallower zones that have the higher permeabilities. In addition, high velocities are induced as water passes down the outside of the casing and these can silt up the borehole and shorten its life.

The present borehole records invariably quote a figure of "yield". The "yield" of a borehole is determined as the quantity of water that can be abstracted from a well given a constant discharge and near equilibrium conditions without exposing the pump base. It does not necessarily reflect any aquifer parameters and some figures may represent the maximum output of the test pump and not that of the borehole. However, these figures do indicate the order of pumping rates that are common within the Kingdom. Table 6 shows a breakdown of the available discharge data. The average yield is 0.91/s from boreholes of average total depth 50m and average static water level 18m.

TABLE 6

"Yield" (1/s)	%age of total (212 wells)
Blank (Dry	13%
(+ 0 - 0.5	33%
0.5 - 1.5	36%
1.5 - 2.5	15%
2.5 - 3.5	2%
3.5 - 4.5	1%
+ 4.5	0%

A rough estimate of the total quantity of groundwater abstracted from boreholes can be made by assuming that each of the known boreholes pump at 0.91/s for six hours per day (abandoned holes may balance those in use for which there is no record). This gives a total figure for abstraction of 3 600m^3/day or 1.3 mcm per year.

Springs, including several thermal and mineral springs occur particularly in the Highveld and Middleveld. Many of the cold springs supply isolated rural communities and some of them have been developed for improved sanitation and discharge, although the observed flow rates are generally of the order of only 1 l/s. The total amount of water discharged from springs and seepages is unknown, but it is likely to be substantially greater than the amount of water abstracted from boreholes because the combined yield of the thermal springs alone is 50 l/s (4 320m^3/day). It is not yet known what percentage of the population are dependent on groundwater supplies nor is it possible to estimate what proportion of total water use is supplied by groundwater. There are no known hand dug wells in the country.

There is very little written information on groundwater in Swaziland apart from the borehole data records held by the Geological Survey and Mines Department. The majority of reports pertaining to groundwater held by Geological Survey relate only to the siting of water boreholes (see numerous reports by J. K. Whittingham and others) and only a few groundwater observations are available.

4.1 Groundwater Occurrence

Water borehole drilling and well digging are not Swazi traditions and this fact coupled with the low yields that have been encountered has discouraged efforts in the past. Furthermore, most of the rocks of Swaziland are not water bearing except where they have been subject to tectonic disturbance, intrusion or chemical breakdown which has opened joints or formed a near-surface permeable zone of weathering (Anon 1974).

The intense patterns of dolerite dykes that occur particularly in the southern Lowveld restrict groundwater flow and limit the recharge areas. However, the baked contact zones of the intrusives are cracked and fractured with a high overall permeability, and this is particularly valuable for groundwater abstraction if it occurs on the upslope side of the hydraulic gradient. Cracks and joints within the sediments act as conduits that can draw on the storage of the country rock, whereas the storage is confined to the volume of the cracks and joints only in less permeable formations (Enslin 1956, 1964).

A recent United Nations Survey (Navarro 1976) overlooked the value of secondary permeability and concluded that "...as a resource, groundwater should in general be discarded in Swaziland". The report lists the limited potential of formations that contain groundwater and implies that without exception permeability values and in some cases also coefficients of storage are inadequate to support useful groundwater abstraction rates.

Aquifer parameters suitable for groundwater abstraction do occur in certain basins of decomposition between fresh crystalline rocks and near surface clays. However, alluvial deposits along river valleys are limited by their physical constraints.

Borehole statistics divided into the major geological systems are given in Table 7. An indication of the order of the specific capacity of the boreholes in a given formation can be obtained by dividing the mean yield by the mean maximum drawdown (static water level minus depth). This will tend towards an underestimate due to the limitations on test pumping equipment which include bailers. Boreholes drilled in the granites have a higher specific capacity (0.046 l/s/m) than those in the Ancient Gneiss Complex (0.033 l/s/m), but this is to be expected because of the consistently higher yields obtained in the weathered granite basins of Malkerns and the Ezulwini Valley. In the Karroo System, boreholes in the sediments have a higher specific capacity (0.028 l/s/m) than those in the lavas (0.023 l/s/m) and this reflects the higher permeability of the sediments.

4.1.1 Pre-Karroo

The Pre-Karroo rocks with the exception of the Insuzi and Mozaan Series are crystalline, massive and impermeable. The higher yielding boreholes intersect joints or are sited adjacent to dykes or basic intrusions, though some draw water from partially weathered rock (Visser 1956). Advanced bedrock weathering producing clays, however, can limit yields in certain areas (Frommurze 1937). Small perennial springs often occur at contact zones with dolerites.

Groundwater in the cracks and joints tends to be semi-unconfined such

TABLE 7

Mean Borehole Data According to the Geology

Formation	No. of B-H's	%age dry	%age <0.5 l/s	Mean depth (m)	Mean water struck (m)	Mean static W L (m)	Mean yield (l/s)
RECENT sediments	0	-	-	-	-	-	-
KARROO Stormberg Series	69	21	61	63	41	24	0.9
Sediments	23	27	50	59	42	19	1.1
PONGOLA SYSTEM	0	-	-	-	-	-	-
SWAZILAND SYSTEM	0	-	-	-	-	-	-
ANCIENT GNEISS COMPLEX	42	9	39	46	30	16	1.0
GRANITES	78	19	46	38	27	12	1.2

that water encountered below the depth of saturation will rise up the borehole according to the head on the water at the point of intersection. The open cracks and joints are often interconnected so that the water within them forms a water table which tends towards a subdued version of the surface topography. A comparison of static water level and water struck data in Table 7 indicates an average confining pressure of 15m.

43% of the boreholes drilled into the crystalline rocks yield less than 0.5 l/s and the average yield is only 1.1 l/s. However, low yields are common in boreholes drilled adjacent to villages, clinics and schools which tend to be located on the tops of ridges (Versey 1977). This is because the ridges are formed by selective erosion and so the degree of weathering within the bedrock is less than that in the valleys where more favourable borehole sites can usually be located.

The highest yielding borehole is at Mpisi where groundwater is drawn through 1mm saw slotted casing from a two metre thickness of baked and weathered granite adjacent to a Pre-Cambrian dolerite dyke. The well has a 24 hour specific capacity of 0.97 l/s/m and the transmissibility of the water bearing zone is 42 $m^3/d/m$. The well can sustain a discharge of 5 l/s indefinitely with a well efficiency of 56% (Robins 1977). Further evidence on the value of secondary permeability is derived from packer tests in foundation exploration boreholes for a dam site on the Black Mbuluzi River, which show that the granite is impermeable away from joint zones delineated by geophysics (Watermeyer et al 1975). A very high degree of secondary permeability in the Swaziland System is illustrated by river flow seepage at a rate of 85 l/s into the Havelock Asbestos Mine (Williamson 1974).

Numerous boreholes in the Ezulwini Valley and the Malkerns Farmlands draw water from the permeable weathered zone overlying the bedrock. Test drilling at Ezulwini revealed an impermeable red clay to 3m depth but below and until bedrock at 20m, the granite gneiss is weathered to a permeable sand. The weathered material is in situ because remnants of quartz veins are exposed in the clay in places. In Malkerns a similar red clay occurs to a depth of about 25m followed by the same sand-like formation to about 30m overlying fresh granodiorite.

The groundwater properties of the Insuzi and Mozaan Series are little known. However, the lavas and shales are likely to be of low permeability and groundwater development may again rely on the existence of secondary permeability.

4.1.2 Karroo and Recent

A shallow homogeneous aquifer occurs at the base of the Karroo and in the upper weathered portion of the underlying rocks (Davies 1966a). The aquifer is insufficient for water supply purposes except in the Mpaka area where abstraction supports a colliery and a refugee camp.

The Karroo sediments are well cemented with a porosity within the range 0.5 to 2.5% (van Wyk 1963). Grain size is variable but there is nothing coarser than medium grained sandstone. Secondary permeability is an essential feature for satisfactory groundwater abstraction and boreholes dependent solely on primary permeability can rarely support even a hand pump. Jointing within the sediments is mainly limited to the shale and coaliferous bands which tend in any case to yield water of unsuitable chemistry for domestic use. Jointing within the volcanics is also limited although the monoclinal structure beneath the rhyolites has produced a series of strike joints which are indicated on the surface by a pronounced topographic lineation carrying a dense cover of vegetation (Cleverly 1977). Open joints tend to be dry away from deep seated dykes and faults and only one in five weathering joints produce water. The water bearing properties of faults can be limited by the presence of clay gouge. The most favourable situation of all, however, is the baked contact zones adjacent to dolerite dykes and these are responsible for 80% of the yielding boreholes. The fractures tend to be open to a depth of about 20m, below which they are closed by compaction.

Enslin (1950) equates the yield of a borehole adjacent to a dyke with the distance of the borehole from the contact. The yield is greatest up to 1m from the contact, and at 3m from the contact the permeability reverts to that of the country rock. Weathering of the dyke itself can also provide some storage, however, sills and sheets are usually unproductive unless the contact is weathered at the point it intersects the water table.

An interesting example of groundwater derived from an igneous contact is the Dokolwayo Kimberlite some 550 x 75m in area which is intruded in granodiorite. The Kimberlite is impermeable and weathered almost to a clay in the upper 40m. However, the adjacent country rock, fractured and brecciated by the intrusion of the Kimberlite, forms a high permeability zone in the immediate vicinity of the pipe. Narrow dykes of Kimberlite trending parallel to the long axis of the major body occur. They vary in width from a few millimetres to a few centimetres and may improve the secondary permeability of the country rock. Four water supply boreholes were sunk along the western contact zone and fourteen day pumping tests proved minimum yields in each hole of 11 to 16 l/s, the highest known yields from water boreholes in Swaziland (personal communication - A. J. Carrington, De Beers Holdings).

Of the 92 boreholes recorded in the Karroo, 21 are dry and 56 yield less than 0.5 l/s. These figures are compatible with those recorded by Visser et al (1947) and Frommurze (1937) for the Ermelo and Barberton areas of South Africa respectively. In the Lowveld, however, the dyke intensity is greatest in the south and groundwater potential is correspondingly higher.

Groundwater is not currently abstracted from alluvial deposits. These deposits are generally narrow and of limited depth, and their potential is not likely to be great except where they might act as a natural filter in river abstraction schemes. The only exception is the scree deposit around Balegane which may be worthy of exploitation though the domestic and irrigation requirements of that area are fully serviced by the Komati River.

4.2 Recharge

No quantitative studies have as yet been made. However, it is unlikely that abstraction exceeds recharge even in areas of greatest borehole density in Malkerns and the Ezulwini Valley, as there is no evidence of declining water levels. In these areas recharge through the shallow clays is unlikely because water levels indicate an immediate response to the rains, and it is more likely that recharge occurs via the peripheral scree deposits and where the clay is locally absent. Elsewhere in the crystalline rocks there are many seasonal boreholes that dry up during the winter months indicating that they draw from a limited storage capacity. However, they usually respond very quickly to the rains which recommence in late spring.

Estimates of recharge cannot easily be made due to inadequate data. By comparison, however, a study on the Middle Ecca has been made in Northern Natal in an area of similar climate and topography to that of the Middle Ecca in Swaziland. This indicates that between 10 and 19% of the average annual rainfall may contribute to groundwater recharge and was based on observations of the discharge from an underground mine working (van Wyk 1963).

Borehole static water levels in the Karroo sediments rise during the summer rains either quickly during and after a storm or slowly throughout the rainy season. It appears that this variation is due to the proximity of the joints penetrated in a borehole to joints that are open to recharge. Recharge to the basalt is not so rapid and depends on prolonged and intensive rain to bring the topsoil to field capacity.

4.3 Thermal Springs

There are ten thermal springs known in the country with temperatures ranging from 33 to 52°C. Robins et al (1978) describes their locations which are also shown in Figure 5. These springs are peculiar in that the last igneous activity was in Jurassic times and consequently the geothermal gradient is low. Krige (1948) measured the temperature gradients in eleven deep boreholes of average depth 1500m in the Transvaal and Orange Free State and observed that the gradients fall within the range of 7 to 14°C per Km with an average gradient of 11.6°C per Km. Nearer to Swaziland at a deep mine working at Barberton the geothermal gradient is increased to 20°C per Km but this is still less than the worldwide mean of 30°C per Km (Turner et al 1951).

All the springs emanate from faults or joints in Pre-Cambrian rock and most have two or three "eyes" although each eye discharges from the same source.

Eight of the springs follow a line trending south-south-west for a distance of 107 Km from Mkoba to Mpopoma. The trend continues to the south-south-west into South Africa through Sulphur Springs (warm); Warm Bad (hot); Natal Spa (hot); to Entembeni (warm), some 200 Km beyond the Swaziland border (Kent 1949). The ninth and tenth Swazi springs are at Siphofaneni and Fairview and they also lie on a line which parallels the first one passing south-south-west into South Africa through Onverwacht (warm); Black Umfolozi (hot); Tugela Valley (scalding); and Lilani (hot). It is probable that these two lines follow some crustal feature that creates two narrow zones of greater than average geothermal gradient. They are parallel to the Lebombo Monocline and may be structurally associated with that, although they do not show any surface expression and tend to cross most known structural trends suggesting that they have only developed recently. Hunter (1968) suggests merely that the trend lines may reflect some deep seated line of crustal weakness.

The discharge and temperatures of the spring waters is shown in Table 8.

TABLE 8

Spring	Discharge (l/s)	Temperature (°C)
Mkoba	4.0	52
Mvuntshini	4.0	45
Ezulwini	6.0	40
Lobamba	3.5	48
Mawelawela	6.0	35
Ngwempisi	3.5	46
Madubula	10.0	52
Mpopoma	4.0	33
Fairview	3.0	38
Siphofaneni	6.0	39

At Mkoba the water emanates from joints in Ag3 granite. The Mvuntshini spring discharges through migmatitic granites and gneisses. The three sources at Ezulwini are in granite gneiss, again from joints and the middle source is adjacent to a dolerite dyke. The three Lobamba springs occur in weathered granodiorite, and at Mawelawela the source is a joint in Ag3 granite. The Ngwempisi spring discharges through alluvium beneath a massive granite boulder, and the Mpopoma spring also discharges through overburden. At Siphofaneni the source is from overburden resting on granite. The Madubula spring emanates from beneath an Ag5 granite boulder in alluvium. The springs discharging through alluvium tend to have the lower temperatures probably due to mixing with cool shallow ground water. Fairview for instance, also discharges through alluvium from mylonitic granodiorite.

The Ezulwini spring, known locally as the Cuddle Puddle, is the only one that is commercially exploited for tourism. The second source at Ezulwini, the three at Lobamba and the two at Siphofaneni have been developed for washing and bathing purposes, but the remainder are not altered in any way.

The discharge water of the springs is meteoric in origin. This has been shown by the relation of Ne, Ar, Kr and Xe concentrations and also δD and $\delta^{18}O$ values (Mazor <u>et al</u> 1974). The noble gases show the waters to have been kept in closed circuit conditions and their concentrations suggest palaeotemperatures at the time of infiltration of between 21 and 31°C. These figures are compatible with the present summer rainy season temperatures. ^{14}C determinations date the waters at between 4,500 and 5,400 years old and in keeping with these figures the tritium content is very low. Analysis of the dissolved gases from the Ezulwini springs suggest that the spring waters contain air dissolved in the water from which oxygen and carbon dioxide have been abstracted by oxidation and carbonation processes underground (Gevers 1965).

Further evidence that the springs at least in the Transvaal are fed by rain water is given by Temperley (1975) who observed that spring discharges correlate to periods of heavy or to periods of low rainfall. In addition the hot springs in South Africa are restricted to areas of higher rainfall (Kent 1969) and all draw on the geothermal gradient as a heat source (Kent 1952).

The springs are, therefore, created by rainwater percolating to great depths which before returning to the surface is heated. In order for the water to increase in temperature by 20°C it would have to circulate at depths of 1,000m and greater, considering heat loss on the upward passage. This assumes that the geothermal gradient is 20°C per km but it may be considerably greater locally because it is unlikely that cracks and joints are open to such depths. It is possible that some exothermic reaction in the country rock, such as the decomposition of sulphides, may also be responsible for the release of thermal energy to the circulating water.

All the springs occur near the bottom of valleys. Most are adjacent to or actually in a bed of a river or stream flowing down the valley. Thus a mechanism for the circulation of the water can be envisaged. Rainwater infiltrates a joint or fault system at some high elevation, perhaps on the valley sides, and flows down to some considerable depth where it is heated by the effect of the geothermal gradient. Under artesian pressure it then flows up a different system of conduits to the lower elevation of the spring. A convection cell may also be set up enhancing the effect of the artesian pressure.

4.4 Hydrochemistry

Broad categories of water types have been established for Southern Africa (Bond 1946). Swaziland, the Eastern Transvaal and Zululand are typified by "pure waters" of normal pH and low salinity. Groundwater in the Lebombo Mountains and Lowveld is characteristically more saline.

In the Highveld and Middleveld the flushing action of springs tends to restrict the build-up of high salinities but older more static water can be quite brackish. Fluoride may be a problem with groundwater supplies in Swaziland, particularly those in the granite areas and in the Ecca Series (Kieser et al 1951). It is always associated with waters dominated by sodium bicarbonate. The highest recorded fluoride concentration is in a borehole at Maloma where 40 mg/l of fluoride is derived from the Ecca Series. At the Ezulwini Hot Spring the fluoride concentration is 31 mg/l and at a borehole in the Lavumisa township 19 mg/l has been recorded. However, these analyses were undertaken in the 1950's and it is not certain what their validity is or what techniques were used to obtain the results. No problems have yet been encountered with high nitrate build-up due to irrigation.

Thirty-two borehole waters are plotted on a Piper Diagram in Figure 6. 25 of the samples were collected in 1978 with bicarbonate titrations done at the well head. The other 7 are analyses reported by Davies (1966b page 44) and some additional data has not been plotted because the cation - anion balance is poor. The 1978 data are given in Appendix 1. The waters largely plot along a straight line between a calcium bicarbonate type and a sodium bicarbonate type (i.e. from 90% Ca 70% HCO_3 to 60% Na 80% HCO_3). The line scatters towards the calcium end and there is a second line of points representing more neutral type waters also due to scattering.

The scattering is due entirely to waters abstracted from the granites. Total dissolved solids range from 30 to 1,007 mg/l and the scatter is due to a higher proportion than normal of chloride to bicarbonate which is not related to the degree of concentration of the ions. The purer waters of the Highveld tend to be acid with pH as low as 4.6.

The granite gneiss yields calcium bicarbonate type water. The total dissolved solids range from 50 to 1,084 mg/l the low values typifying the Highveld. The granodiorite is principally a calcium/sodium bicarbonate water. It tends to be extremely pure with total dissolved solids within the range 65 to 99 mg/l. Water from the Karroo sediments ranges between 1,176 and 1,526 mg/l and are dominantly magnesium bicarbonate to sodium bicarbonate waters. The Karroo basalt water has total dissolved solids in excess of 1,000 mg/l and is a magnesium bicarbonate water. The rhyolites yield calcium bicarbonate type water with total dissolved solids between 497 and 623 mg/l. Dolerite and the Schists yield magnesium bicarbonate water of variable total dissolved solids concentration.

Also plotted in Figure 6 are data from 6 of the thermal springs. Springs emanating from bedrock are sodium bicarbonate waters and Mpopoma and Siphofaneni which emerge through overburden are sodium chloride type. The gas hydrogen sulphide is detectable at most of the springs and is driven off when acid is added to the water. The waters are consequently alkaline with pH usually of the order 9.

5. GROUNDWATER DEVELOPMENT

5.1 Administration

The Geological Survey, Water and Sewerage Board, Public Works Department Hydrology Division and occasionally other government agencies are all engaged in groundwater development.

5.1.1 Geological Survey and Mines Department

A groundwater development unit was established within the Department in 1974. Its major function is to site and drill boreholes on Swazi Nation land for isolated rural communities in the Lowveld. Detailed geological and geophysical surveys assist borehole site selection which is followed by drilling, and the installation and maintenance of hand operated pumps. Additionally, the unit selects borehole sites for government and the public, and it also provides advice on borehole construction and contractural matters. It maintains the borehole records and is involved in groundwater resource assessment through a routine monitoring programme.

The leader of the unit is a Canadian trained geologist who is primarily engaged in borehole site selection. He is assisted by a geophysicist and between them supervision is maintained over two field parties. In addition, one drilling crew comes within the unit who report directly to the Drilling Superintendent (the post is currently vacant and the Trainee Drilling Superintendent is in charge). The Drilling Superintendent is also in charge of two diamond exploration rigs and a powered auger, which are usually engaged on mineral exploration work.

Equipment purchase has been assisted by British Aid funds and advice has been available from resident TC hydrogeologists during the initial years of the groundwater development programme. The geophysical equipment consists of an ABEM Terrameter, a Jalander magnetometer and a proton magnetometer, and down-the-hole salinity and temperature logging equipment is currently on order. Groundwater monitoring equipment includes water level indicators, specific electrical conductance bridges and four Munro autographic recorders. Routine survey equipment including a theodolite is also available. The drilling unit is a heavy duty Mangold (South Africa) percussion rig for which a selection of spares, tools, accessories and test pumps, and a stock of casing are maintained. The diamond drill rigs have also been used for water well drilling for the production of narrow diameter observation wells.

5.1.2 Water and Sewerage Board

This is a quasi-government agency responsible for the development, operation and maintenance of all public water supplies. The major effort is directed towards surface water abstraction and reticulation. The Rural Water Supplies Branch of the Board is responsible for smaller projects aimed at providing water for the rural communities and services. These involve surface water supplies, spring development and borehole abstraction along with reticulation and maintenance. Priority tasks include police border posts, schools and clinics, and close liaison is maintained with the Ministry of Education on their current development and construction programme.

The Rural Water Supplies Branch is funded largely by the Ministry of Overseas Development and the Canadian International Development Agency, but the expatriate staff are almost entirely Canadian. A senior engineer supervises the development programme under the direction of a committee which includes both technical advisors and District Administration officials. Each completed scheme is handed over to the Maintenance Branch and added to the existing schedules for periodic testing and overhaul by two mobile field based units.

Groundwater development is undertaken using the borehole site selection facilities of Geological Survey wherever possible. Drilling is largely let to contract, and although the Boards own percussion rig has been used for shallow drilling in soft formation its major function is now borehole maintenance.

5.1.3 Public Works Department

The Hydrology Division is primarily responsible for meteorological records and maintenance of the river gauging network. Advice on borehole site selection and groundwater potential is given on request to other government agencies, although the Division has neither the staff nor the equipment with which to do this work.

5.1.4 Ministry of Finance

This Ministry has expressed concern for the apparent duplication of effort in groundwater development. Direction on future planning is given on advice from outside authorities such as the United Nations.

5.1.5 Other Government Agencies

Any government agency can, at its own discretion, by-pass the recognised groundwater development authorities and drill boreholes as required under contract. This practice is declining.

5.2 Borehole Site Selection

Site selection investigations are carried out free of charge by the Geological Survey Department. No other surveying teams are available although South African consultants have occasionally been used in the past. Many private boreholes are sunk on sites recommended by the driller and three water diviners are active in the country, often with considerable success.

Heavy reliance is placed on air-photo interpretation in order to identify dykes and joint systems. This is followed by geological ground checking and where necessary also by geophysics. Electrical resistivity surveying is most commonly used due to its low cost and ease of operation. Wenner configuration depth soundings are made to delineate the depth of weathering and occasionally constant separation traverses are employed to locate vertical boundaries such as dyke contacts. Geological control from existing boreholes is minimal and is the major limitation of the technique. Dykes are more commonly located with magnetic traverses but the technique cannot always be relied upon because some dykes, particularly those of Pre-Cambrian age, do not possess a magnetic anomaly. The absence of an anomaly is quite unusual and is probably due to the breakdown of magnetised materials by weathering and low grade metamorphism.

There are other geophysical methods which may prove worthwhile. These include the electromagnetic technique which should be capable of delineating water filled joints and fractures particularly in low permeability formations, and the seismic method, although its cost and speed of operation may be prohibitive.

Much emphasis has been placed on resistivity surveying in South Africa. Van Wyk (1963) shows that the most favourable strata in the Karroo sediments for groundwater abstraction, usually with open jointing, are those where the apparent resistivity is within the range 500 to 2000 ohm-metres. Enslin (1950) has shown that the yield of a borehole near an intrusive contact is proportional to the distance from the contact. Resistivity surveying should become more valuable in Swaziland when more borehole data are available from which control spreads can be made within each survey area.

5.3 Drilling

There are four water borehole drilling rigs based in Swaziland. Three are percussion or cable and tool rigs, of which two are operated by Government and one by the Manzini based contractor Keir and Cawder Ltd. The fourth is an air percussion rig operated by Ropot Drilling of Msimpofu. Occasional foreign contractors operate in the country usually with air percussion equipment. Contract drilling of a 150mm diameter uncased borehole is undertaken at between E17 and E20 per metre (between £Stg 11 and £Stg 13), and contrasts favourably with government operation costs for a borehole of similar construction which are in the order of E210 (£Stg 140) per metre. These figures are exclusive of siting costs, but include fuel and wages. Plant depreciation is not accounted for in the government costs. The excessive cost of the government operations is largely due to wages accrued in standing time, transport to and from the site on Mondays and Fridays, plus additional journeys and standing time accrued by having the bits redressed under contract in Mbabane.

The drilling contractors work in the private sector without supervision. As a matter of course, they always plain case newly completed wells to bedrock even though machine slotted casing is available locally. Two examples in the Malkerns area show the futility of this: where an air percussion rig was blowing a 1 l/s but the test yield after casing the well was only 0.1 l/s, and where a bailer test completely drained a cased well only 10 metres from another hole of similar depth and capable of a sustained yield of 3 l/s.

In general the standard of contractors work is poor although there is no reason why it cannot be brought to the standard of government drilling given adequate supervision. The main advantages of letting work to contract is speed of operation and economy.

Drilling contractors are not obliged to submit records of newly completed wells to Government, although information is received on an informal basis. It is believed that about 80% of all existing water boreholes are on record at the Geological Survey. For each well, the data are duplicated on a record sheet and an abbreviated record card. Numbers are allocated according to the 1:50,000 scale sheet number (there are 31 sheets) followed by a numerical identity. For instance, borehole 17/47 is the 47th borehole recorded on the Malkerns Sheet, number 17. A national borehole density map and 1:50,000 scale maps for the areas of greater borehole density are updated periodically.

5.4 Groundwater Resource Assessment

Meteorological and hydrological data are generally insufficient for water balance equations and soil moisture deficit analyses to be sensibly undertaken, and consequently a simpler approach has been made. Narrow diameter cored boreholes have been sunk in selected areas in order to monitor groundwater level and chemical fluctuations with time. Precise lithological logs have been constructed for each hole along with an exact record of casing and screen. The boreholes are at Ezulwini, Malkerns and Mpaka and they are each equipped with autographic recorders. A fourth borehole at Big Bend is periodically measured with a water level indicator.

The three autographic recorders are in areas of intense groundwater abstraction and in time they should indicate if overpumping is occurring or conversely if greater development can take place. The long term hydrographs should enable water balances to be made.

Detailed groundwater resource assessment is not warranted at present. Wright (1978) states that the hydrogeological conditions and the general availability of surface water supplies make it difficult or generally unnecessary to prepare very accurate groundwater resource analyses. With the exception of the Ezulwini and Malkerns basins of decomposition, groundwater is compartmentalised by intrusives and tends to occur in isolated fracture and fissure systems. Water table and chemical maps could usefully be prepared of the Ezulwini and Malkerns areas to delineate areas of recharge. However, this is no easy task, as Versey (1977) points out, insufficient boreholes provide access to the casing to enable periodic or even single static water level measurements to be made.

6. RECOMMENDATIONS AND CONCLUSIONS

The value of groundwater as a resource in Swaziland has not yet fully been realised, but it will provide many rural communities with a potable water supply. Although a certain amount of groundwater is drawn for non-domestic purposes, for instance by Libby's for their cannery at Malkerns, the majority of existing and proposed installations supply isolated communities and ranches, many of which are long distances from perennial surface water supplies. Some of these communities can be supplied adequately by a hand pump and a low yielding borehole at moderate cost for equipment, operation and maintenance. As living standards are raised the supply can be improved by further drilling if necessary, or the installation of more sophisticated pumping equipment.

6.1 Recommendations

6.1.1 Geological Survey and Mines Department

Groundwater data collection, borehole site selection and drilling on sites of hydrogeological interest should be maintained by this Department. At present a Mangold percussion rig is in operation on hire from the Central Transport Organisation. However, drilling costs are extremely high owing to inefficient working routine (three day week), lack of incentives to the crew and lack of back-up facilities. It is recommended that the hire of this rig should cease if efficient working cannot be maintained and that the rental and crew be offered to the Water and Sewerage Board. In its stead and at far less cost to the 'Department, production drilling for rural communities and Government, as well as exploratory drilling for hydrogeological purposes can be undertaken by contractors under the supervision of the Drilling Superintendent. This would require perhaps a two month contract to drill ten boreholes in any twelve month period.

Borehole completion designs must be improved. The incorporation of a suitable length of well screen (1mm slot should suffice) placed adjacent to zones suspected to be of relatively high permeability should greatly improve well specific capacities. Non-ferrous casing and screen may be used to advantage and PVC or GRP pipe which is light and easy to handle is also less expensive than the equivalent steel casing.

The existing borehole site selection routine should continue largely as at present. Collated field data and reports should be indexed and properly stored. Greater emphasis on photogeology and geological ground surveying should be made but under no circumstances should a geophysical survey precede this work. Thorough and regular checking of the Terrameter should be undertaken on a prevention rather than a cure basis. The electromagnetic and seismic techniques may prove useful additions to the existing techniques. Arrangements for suitable equipment to be demonstrated, particularly in the Lowveld, should be made with a view to possible purchase (IGS may assist in this matter).

Borehole site selection cannot presently keep apace with drilling requirements. However, site selection techniques can be improved and time can be saved by the more careful application of field methods. This will require the geophysicist or a suitably trained technician to be on site at all times. Each field party should be capable of siting one borehole per week except in cases of extremely complex geology.

The basic groundwater monitoring programme should continue. When suitable boreholes that are not required for pumping become available, they should be added to the existing well round for periodic static water level measurement and testing of depth samples for specific electrical conductance. Further chemical analyses of groundwater should be undertaken annually so that any change in the chemistry can be observed and so that samples can be taken from new areas. This work should involve about 25 samples per year. No suitable facilities exist locally that can provide sufficient accuracy, but IGS may be able to assist with the analyses. Eventually chemical maps and charts of various chemical concentrations against time can be constructed.

A proposed amendment to the Water Act should be pursued to assist data collection from newly completed boreholes and existing ones. This is best undertaken by Geological Survey as they hold the existing records and these are necessarily of a geological nature. Such legislation will require the appointment of a clerical officer to maintain the records and relevent correspondence, and a water bailiff to undertake field inspections.

It is not anticipated that regional hydrogeological mapping would usefully benefit groundwater development. Aquifers as such do not exist with suitable parameters for abstraction except in the Ezulwini Valley and at Malkerns. Access to borehole casing is limited in these areas and at the moment prohibits any such work being undertaken. Elsewhere groundwater is generally confined to secondary features of permeability with small compartments of low yielding rock between them. Low borehole density again prohibits mapping these areas. However, hydrographs from the four observation boreholes along with others that may be added in due course should prove sufficient to determine local recharge availability.

6.1.2 Water and Sewerage Board

Attempts by this Department to procure the groundwater development unit from Geological Survey should be discouraged. The transfer of staff from a geological to an engineering environment as well as isolating them from their records would be detrimental.

Drilling should continue to be undertaken by contractors. Proposals to purchase an air percussion rig should not be pursued because there is insufficient work to employ such a rig full time and site selection delays would further limit its activity. Besides, problems of maintenance and staffing would inevitably arise. The new Drilling Superintendent at Geological Survey can supervise contractural matters as has been the case in the past. (A request should be made to the Ministry of Overseas Development, London that this is noted on the new Drilling Superintendent's letter of appointment.) The acquisition of a second percussion rig (see 6.1.1) will assist in pump maintenance work. Assistance in the operation of these rigs can again be drawn from the Drilling Superintendent.

If possible requests for borehole sites should be made with Geological Survey as much as twelve months before drilling is anticipated to allow for appropriate work planning. Drilling on sites not recommended by Geological Survey should cease in order to reduce overall production costs.

6.1.3 Public Works Department

The Hydrology Division, Public Works Department should cease all attempts to act as an agent for groundwater development because the Division is ill equipped to do this work and has no suitably trained staff. Any future queries regarding groundwater should be transferred to either Geological Survey or the Water and Sewerage Board and the enquiring Department advised accordingly.

There may be merit in holding a duplicate copy of the borehole record collection for security purposes and the convenience of the public. This should be encouraged if interest is maintained in obtaining the record system.

6.2 Conclusions

Swaziland is a small country with a varied topography and climate. Geologically it can be divided into the Pre-Cambrian and the Karroo although there are many broad variations within these divisions. The most successful area for groundwater abstraction are the decomposed basins within the crystalline rocks at Ezulwini and Malkerns, although whether recharge keeps pace with abstraction is as yet unknown. Apart from these areas most groundwater is abstracted from some secondary feature of permeability such as joints or baked and fractured zones adjacent to intrusions, and virtually no groundwater is abstracted directly from the Pre-Cambrian or Karroo rocks.

Borehole site selection depends heavily on the location of secondary features within a given formation. Air-photo interpretation and geophysics are useful tools but geological ground surveys are an essential prerequisite to a successful site being found.

Borehole sites selected for hill and ridge top communities should include a thorough survey of nearby valley areas even though mechanical pumping techniques would have to be used if the lower sites were selected and successful.

Borehole pumping yields are less than 5.0 l/s (except 11-16 l/s pumped from the Dokolwayo boreholes), and average 0.9 l/s. Average borehole depth is 50m with water rising to 18m within the borehole. Borehole design tends to be poor with plain casing often placed to bedrock so restricting groundwater from entering the borehole. This is reflected in the specific capacity of most wells which tend to be in the order of 0.02 l/s/m whereas a properly designed and screened well at Mpisi has a specific capacity of 0.97 l/s/m.

Cold springs and seapages tend to be of limited discharge although some of the thermal springs support more substantial flow. All the springs emanate from joints or similar secondary features of permeability within the bedrock. The thermal springs are derived from meteoric water percolating to great depth to be warmed before rising to the surface.

The groundwaters of the Highveld tend to be very pure commonly with total dissolved solid concentrations less than 100 mg/l. Highest concentrations (1,000 to 1,500 mg/l) are found in the granites of the Middleveld and

Karroo sediments. Fluoride may be a hazard in parts of these regions.

Groundwater abstraction amounts to an estimated 3,600 m^3/day or 1.3 mcm per year. This is equivalent to a single borehole pumping at 42 l/s, and the present day contribution from groundwater supplies is, therefore, only small. Nevertheless, in order to ensure that supplies are maintained and safeguarded and in order to determine what further development can take place (if indeed overpumping is not already taking place in certain areas) monitoring programmes have been commenced that will enable recharge and water balance equations to be determined in selected areas.

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APPENDIX 1

Hydrochemical Data (All concentrations in mg/l)

SEC µmho/cc	pH	Temp °C	HCO_3	SO_4	Cl	NO_3	F	Ca	Mg	Na	K	Balance %
Borehole No. - Location - Geology												
BH 5/2 - Oshoek Garage, Highveld - Granite												
116	5.9	21	39.0	0.4	8.7	3.0	0.2	5.4	2.9	7.8	1.1	-3.6
BH 5/3 - Motshane Store, Highveld - Schists												
79	6.6	23	40.3	0.2	16.5	2.0	0.1	5.8	8.8	4.0	0.2	1.3
BH 5/4 - Komati Camp, Highveld - Granite												
37	4.6	20	9.8	0.8	8.5	3	0.1	4.5	2.2	5.2	1.6	18.2
BH 6/2 - Endengeni, Highveld - Granite												
36	5.1	23	8.1	0.3	7.7	4	0	2.4	2.5	3.8	1.4	11.2
BH 7/5 - Mliba, Middleveld - Granite												
1562	6.7	27	283.0	3	50	13	2.1	25	19	78	1.4	-0.7
BH 8/22 - Nkalishane, Lebombo - Rhyolite												
595	6.7	27	329.4	0.1	35	4	1.7	56	14	57	1.2	0
BH 11/8 - Happy Valley, Ezulwini - granite gneiss												
214	6.8	24	65.0	1.0	8.9	6.7	0.4	12.6	5.5	7.2	1.2	-0.7
BH 11/21 - Yen Saan, Ezulwini - granite gneiss												
73	6.5	24	30.0	0.8	8.7	3.8	0.2	5.3	2.5	4.8	0.8	-7.6
BH 11/27 - Codec, Ezulwini - granite gneiss												
61	6.3	24	30.0	0.4	7.2	0.2	0.3	5.2	2.7	4.2	0.5	-2.1
BH 11/30 - Diamond's Valley, Ezulwini - granite gneiss												
74	6.1	23	32.0	0.5	8.8	-0.1	0.3	5.0	2.7	5.6	1.0	-2.9
BH 12/2 - Manzini, Middleveld - Granodiorite												
102	8.3	25	26.8	2.8	5.7	1.0	0.2	7.2	3.4	0.4	1.4	1.3
BH 12/16 - Haven Rest, Middleveld - Granodiorite												
209	6.1	26	92.7	0.3	16	8	0.4	11	9	21	1.4	3.1
BH 12/17 - Hi Way Motel, Middleveld - Granite												
620	6.6	26	309.9	0.3	35	10	0.7	41	35	23	1.8	-2.2
BH 13/9 - Mpaka, Middleveld - Karroo Sediments												
1748	7.8	26	641.7	5	229	11	1	114	90	84	1.4	-1.4
BH 13/14 - Ngogola, Middleveld - Granite												
1720	7.6	25	417.2	2	276	17	0.6	69	61	160	4.6	2.0
BH 13/18 - Mpisi, Middleveld - Granite												
452	6.6	26	234.2	0.5	45	3	0.5	32	24	34	1.6	-0.7
BH 17/1 - Nyanza, Malkerns - Granodiorite												
122	6.1	24	56.8	1.1	11.3	2.9	0.6	8.2	5.6	12.1	0.6	3.4
BH 17/7 - Ross Citrus, Malkerns - Granodiorite												
113	6.6	23	54.0	1.8	8.9	0.6	0.2	6.6	3.9	12.7	0.6	1.4
BH 17/33 - Malkerns Club - Granodiorite												
114	6.1	23	56.8	0.9	10.4	1.4	0.3	8.7	3.3	10.4	1.2	-3.1
BH 17/48 - Malkerns - Granodiorite												
83	6.8	23	38.0	1.5	7.7	1.2	0.5	5.0	2.6	8.4	1.0	-2.1

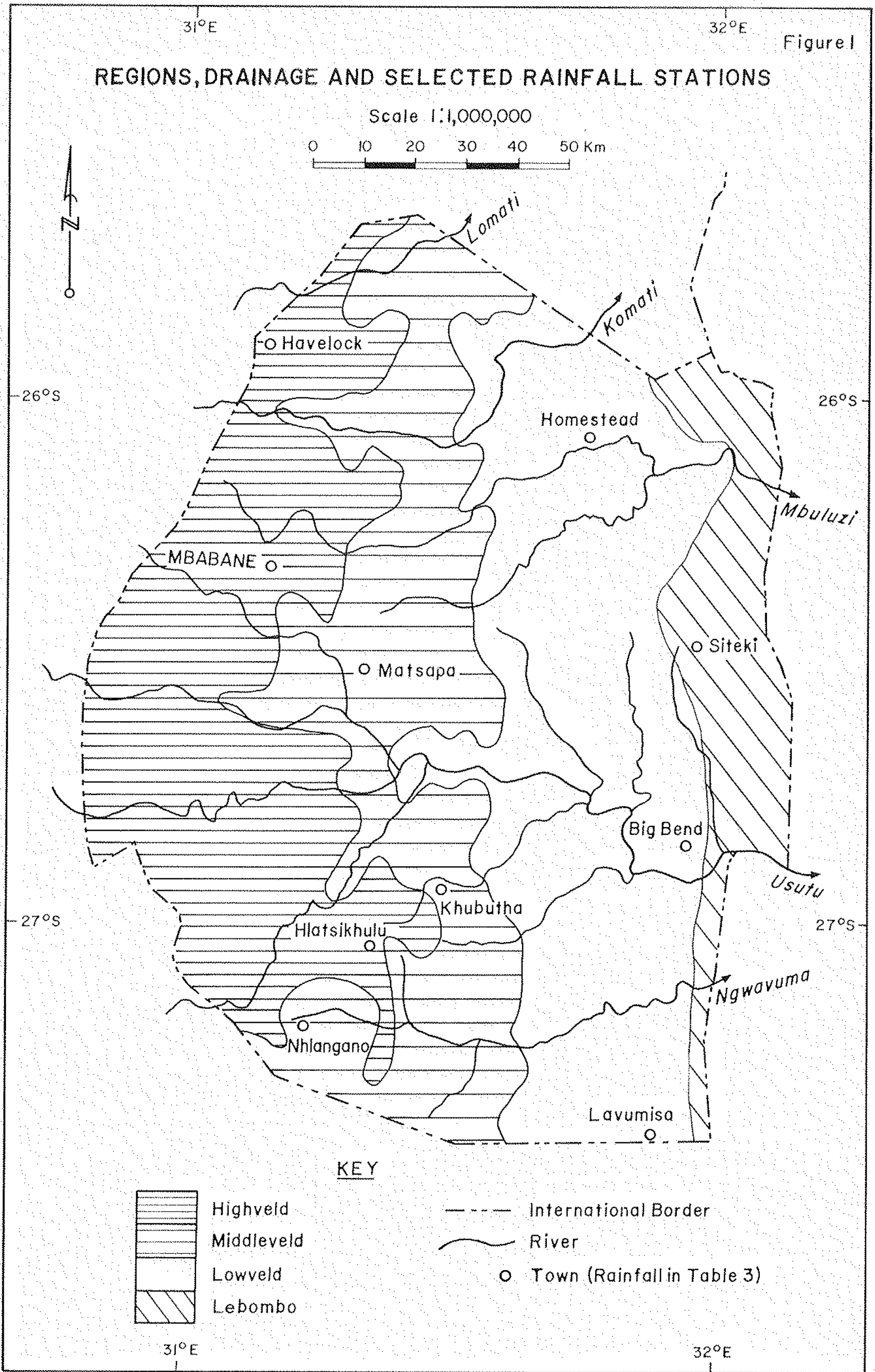
Appendix 1 (contd.)

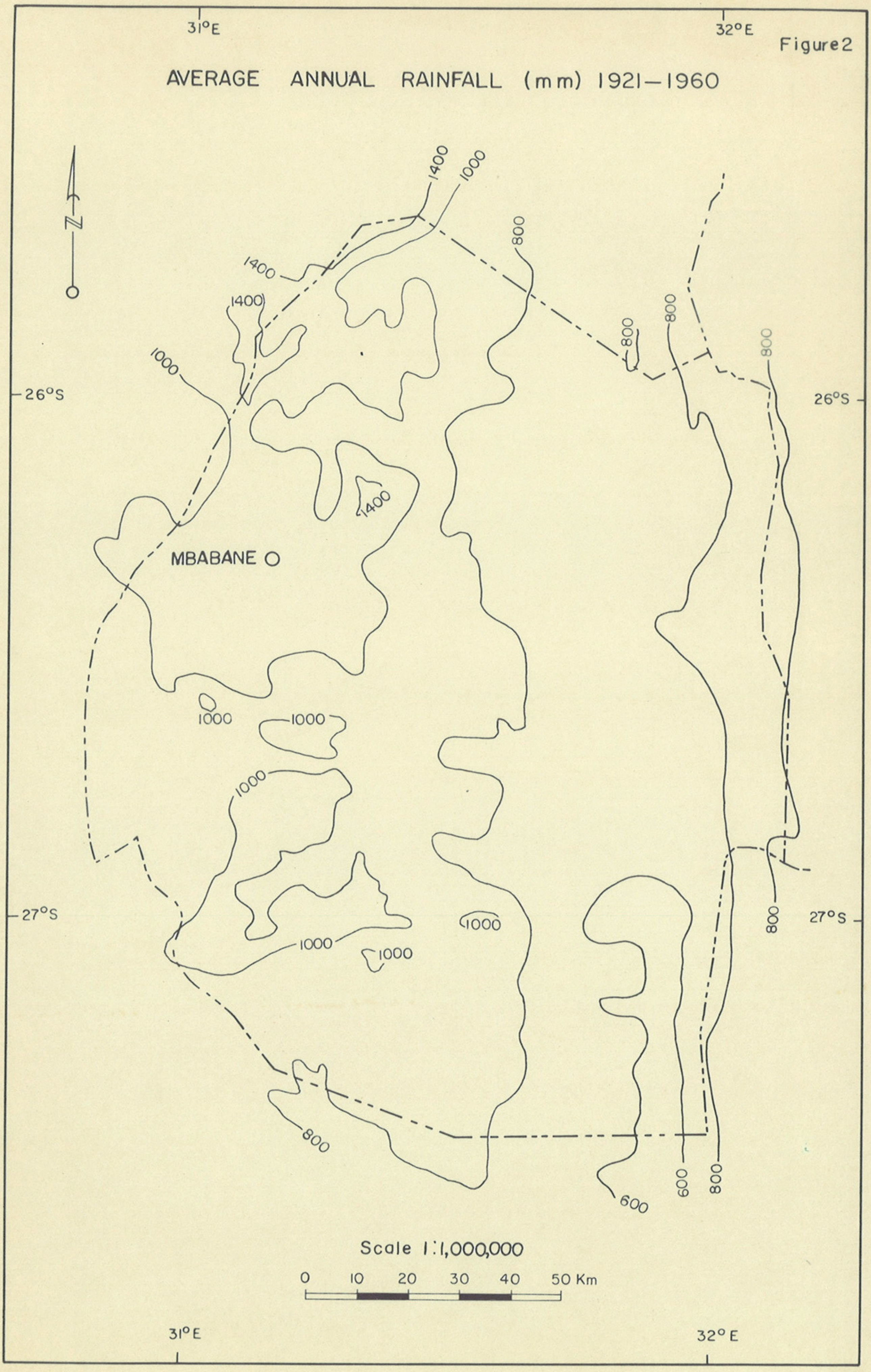
Borehole No. - Location - Geology												
SEC μmho/cc	pH	Temp °C	HCO_3	SO_4	Cl	NO_3	F	Ca	Mg	Na	K	Balance %
BH 19/2 - Gilgal School, Middleveld - Granite												
955	6.8	25	284.3	3	137	62	1.4	29	26	140	2.2	0.8
BH 20/2 - Shoba, Lowveld - Karroo Sediments												
1740	6.8	27	956.5	5	150	4	1.0	61	53	296	0.7	0.6
BH 25/1 - Sitobela, Middleveld - Granite gneiss												
1530	7.0	26	622.2	3	133	45	0.8	67	56	156	1.4	0.1
BH 26/1 - St. Phillip's, Lowveld - Dolerite												
1540	7.3	24	756.4	15	183	0.5	0.3	130	84.0	81.9	0.6	-2.6
BH 26/2 - Big Bend, Lowveld - Karroo Basalt												
1540	6.9	27	551.4	29	107	96	0.5	108	76	73	0.8	2.2

Major ion analyses by the Geological Survey Department, Lobatse, Botswana

Figure I

REGIONS, DRAINAGE AND SELECTED RAINFALL STATIONS




31°E
32°E
Figure 2
AVERAGE ANNUAL RAINFALL (mm) 1921–1960
N
1400
1000
800
1400
1400
1000
800
800
800
26°S
26°S
1400
MBABANE
1000
1000
1000
1000
1000
1000
27°S
27°S
800
800
600
600
800
800
Scale 1:1,000,000
0 10 20 30 40 50 Km
31°E
32°E

GEOLOGY OF SWAZILAND AND THE ADJACENT AREAS

Figure 3

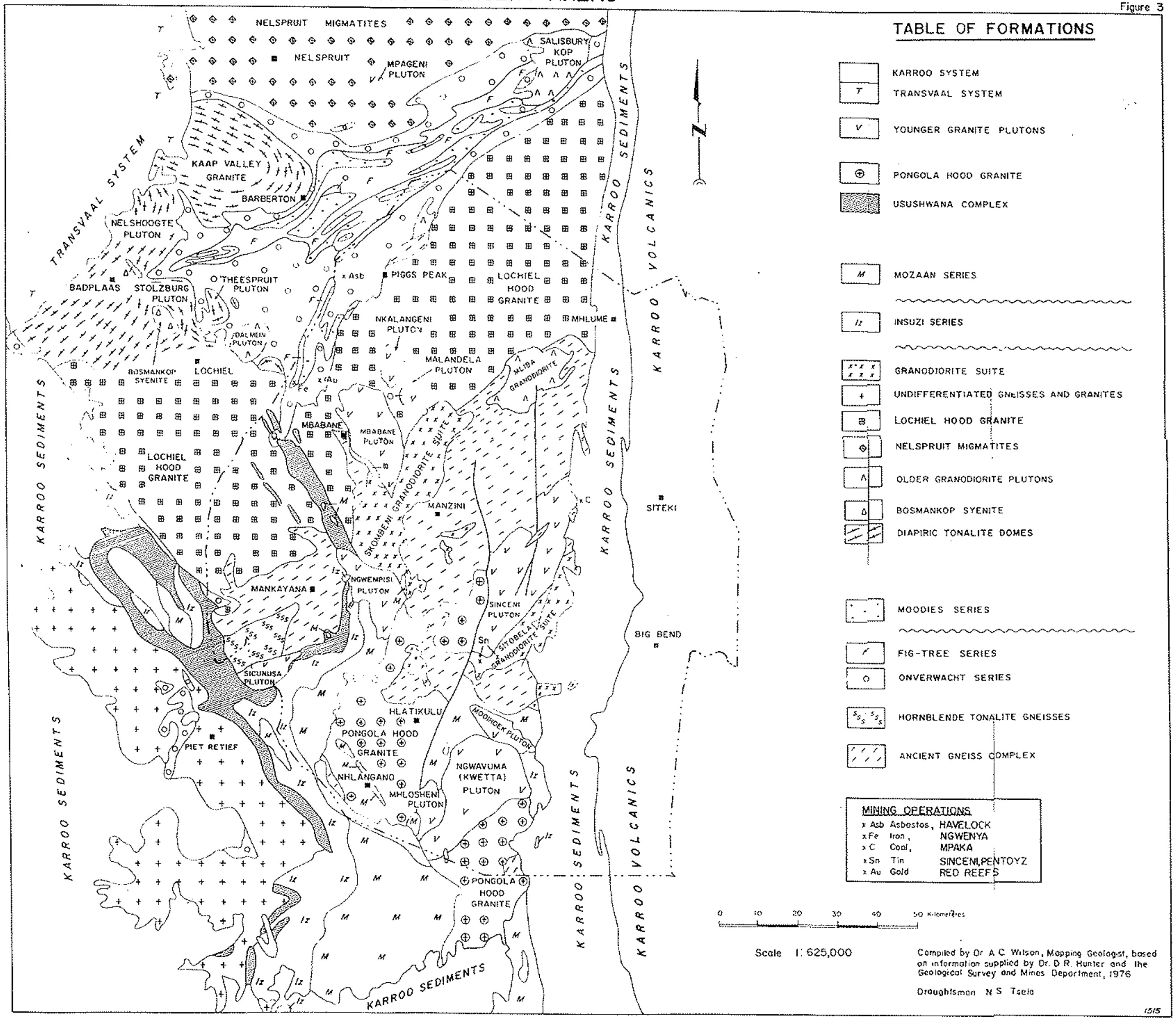
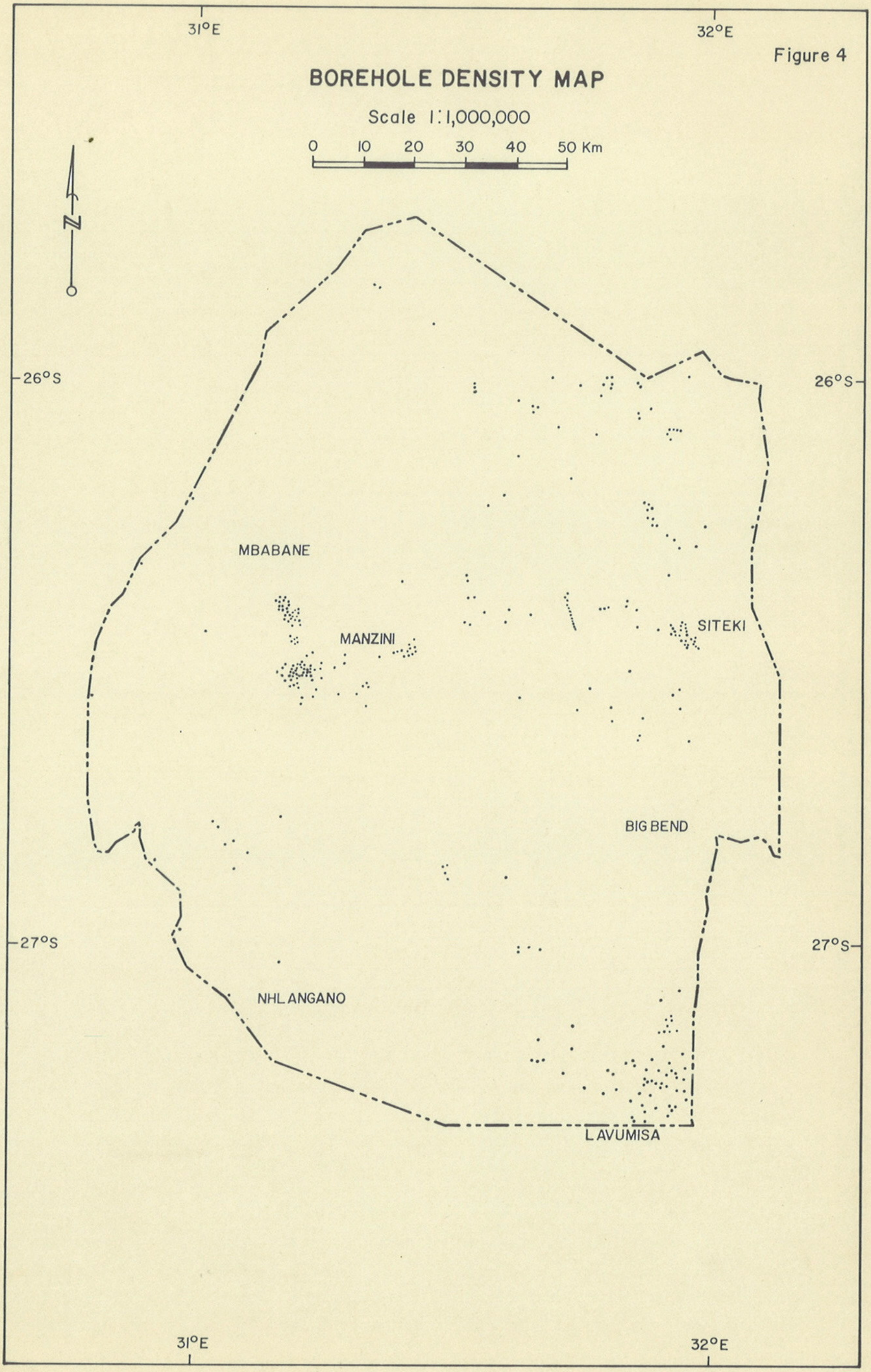


Figure 4


31°E
32°E
BOREHOLE DENSITY MAP
Scale 1:1,000,000
0 10 20 30 40 50 Km
N
26°S
26°S
MBABANE
MANZINI
SITEKI
BIG BEND
27°S
27°S
NHLANGANO
LAVUMISA
31°E
32°E

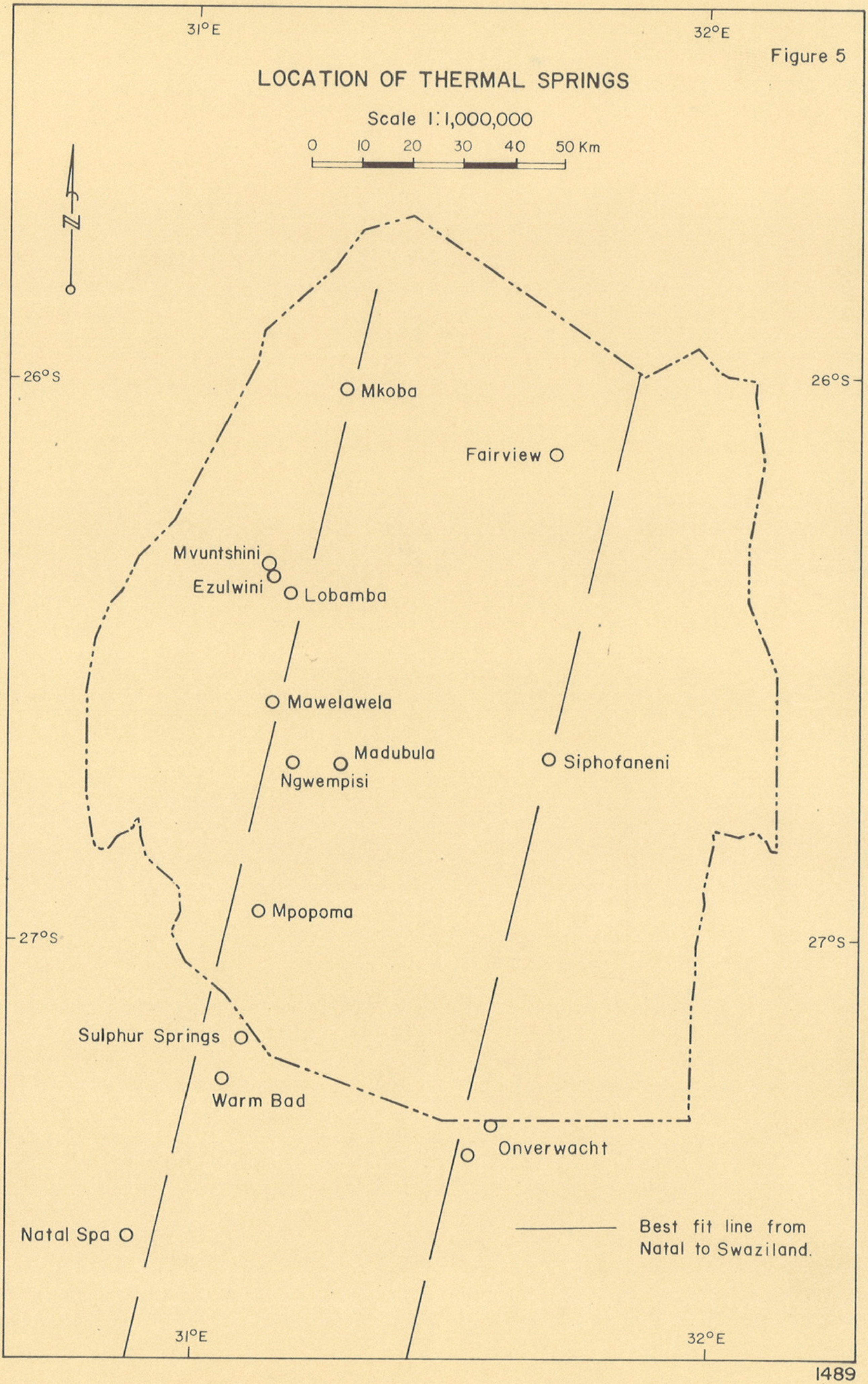
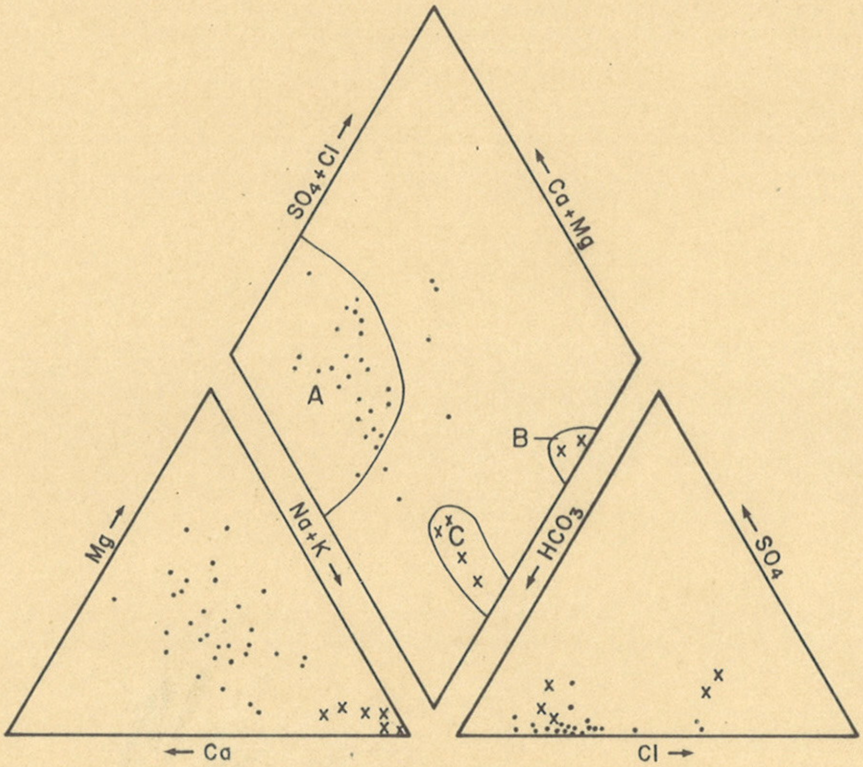

31°E
32°E
Figure 5
LOCATION OF THERMAL SPRINGS
Scale 1: 1,000,000
0 10 20 30 40 50 Km
N
26°S
Mkoba
Fairview
Mvuntshini
Ezulwini
Lobamba
Mawelawela
Madubula
Ngwempisi
Siphofaneni
Mpopoma
27°S
Sulphur Springs
Warm Bad
Onverwacht
Natal Spa
Best fit line from
Natal to Swaziland.

Figure 6



KEY

- • Borehole (32 Samples)
- x Thermal Spring (6 Samples)
- A Calcium Bicarbonate Type
- B Sodium Chloride Type
- C Sodium Bicarbornate Type

PIPER DIAGRAM OF TYPICAL GROUNDWATER CHEMISTRY