GROUNDWATER RESOURCES OF SWAZILAND

SWAZILAND MINISTRY OF NATURAL RESOURCES, LAND USE AND ENERGY

CANADIAN INTERNATIONAL DEVELOPMENT AGENCY

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GOVERNMENT OF SWAZILAND

DEPARTMENT OF GEOLOGICAL SURVEYS AND MINES

CANADIAN INTERNATIONAL DEVELOPMENT AGENCY

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TEAMWORK PRODUCES ANOTHER SUCCESSFUL BOREHOLE

EXECUTIVE SUMMARY

A significant step forward has been made in delineating the extent of the groundwater resources of Swaziland. Based on the data obtained by the Groundwater Survey Project team, it is clear that the resource is substantial, and that there is considerable potential for future exploitation. However, because of the complexity of the water-bearing strata, development will require the continued efforts and cooperation of both the government and the private sector, utilizing proven methods for exploration, abstraction and management.

A groundwater survey was carried out between 1986 and 1981 by the Swaziland Department of Geological Surveys and Mines, with the assistance of the Canadian International Development Agency. The survey involved geological and geophysical surveying of potential borehole sites, drilling 395 boreholes, hydraulic and chemical testing of groundwaters, and establishment of a computerized database. Twenty-seven 1:50,000 scale and one 1:250,000 scale hydrogeological maps, covering the entire country, were compiled.

Based on this survey, the water-bearing subsurface strata in Swaziland has been divided into twenty-four major hydrogeologic units, with many sub-units. Of these units, the most productive are the Greenstone Belt (GB), Mozaan (MZ), Weathered Basalts (BA/WE) and Fault Zones (FZ), all of which have average borehole yields in excess of 2 L/s. With the exception of Weathered Basalt, these units are principally located in the Highveld area of Swaziland. There are records for about 1,400 boreholes in Swaziland, of which about 946 have yield information. The average borehole yield is 1.4 L/s, and individual blown yields (i.e. short term) range from virtually dry, up to about 20 L/s.

Long term yields for individual boreholes will depend on a number of factors, including permeability of the strata; geographic location; sources of recharge; available subsurface storage capacity; and the number of other boreholes abstracting water from the same zone. In general, it is anticipated that the long term yield of each borehole will decline from the short term blown yield values, determined as part of the Survey. However, the amount of decline will be highly variable, and can only be evaluated on a site by site basis.

Groundwater flow systems in Swaziland are mostly shallow, and residence times are believed to be relatively short (less than a few tens of years). There are numerous springs and seeps, located primarily in the Highveld and Lebombo areas. Typically, the cumulative groundwater discharge from local strata sustain a modest perennial flow in most of the small streams draining these regions, even during extended dry seasons. It is estimated that groundwater recharge is between about 0.5 and 15% of average annual rainfall in the basin areas of Swaziland. These represent recharge fluxes of between about 0.05 and 5 $L/s/km^2$ (litres per second per square kilometre).

The estimated total potential groundwater resource in Swaziland is equivalent to a sustained flow of 20.5 cubic metres per second (20,500 L/s). To date, only about 6% of this potential has been tapped. The Middleveld and Highveld areas of Swaziland have the highest potential for groundwater exploitation.

In general, groundwater quality meets World Health Organization (WHO) Drinking Water Standards, especially in the Highveld and Lebombo regions. A typical hydrogeochemical evolution of groundwater is from a calcium-magnesium-bicarbonate type groundwater in the recharge areas, towards a sodium-chloride type water in the discharge areas. In the Lowveld, where evapotranspiration rates are high and the rate of groundwater flushing is low, groundwaters tend to become relatively salty, commonly with total dissolved solids in excess of 1,500 mg/L.

Groundwater fluoride concentrations are elevated in some localities, with concentrations consistently exceeding 3 mg/L. However, in most of the country, fluoride concentrations are less than 0.5 mg/L, which is significantly lower than the WHO limit of 1.5 mg/L. There is little correlation between fluoride concentration and hydrogeologic unit types or areas where fluorspar minerals are present. Fluoride concentrations tend to be highest in the Lowveld area, where the total dissolved solids content in groundwater is also elevated.

Nitrate concentrations in groundwater ranged up to 38 mg/L, and averaged 3.8 mg/L. Higher nitrate concentrations were mostly found in Lowveld region groundwaters. As with fluoride, there is no simple correlation with hydrogeologic units; however, there is a strong correlation with total dissolved solids. The most probable source for the nitrogen is a result of fixation in the soils around the leguminous trees and shrubs of the Acacia species, which are most common in the Lowveld area.

Now that the groundwater resources of Swaziland have been assessed and techniques for locating the higher yielding and better quality areas have become more advanced, it is likely that groundwater will be utilized more extensively. This will greatly assist with the development of the rural areas, by providing both a well filtered drinking water source and a reliable source of water for small scale agricultural irrigation projects.

In order to properly manage the resource, it will be essential that water-bearing zones are protected from pollution and abstraction rates exceeding natural rates of replenishment. As there is clearly a strong relationship between surface and groundwater flow, there is an additional need to ensure that surface water rights are not compromised by over-development of the groundwater reservoirs. The task of preserving groundwater quality and managing the abstraction rates will be more effective once the proposed National Water Authority has been established.

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1. INTRODUCTION

1.1 WATER SOURCES

Swaziland receives a reasonable amount of rainfall over much of its territory; however, its frequency and distribution throughout the year is rarely sufficient to avoid drought conditions in low lying areas. During the dry season, the people of Swaziland invariably have to rely on the larger rivers, springs, and water stored in the few ponds or lakes for their water supply. Most streams in the Lowveld area typically flow only intermittently during the wet season, and dry up completely during the dry season. This has meant that local residents have either had to move, or be prepared to carry water over long distances.

Many of the large rivers have headwaters in the Republic of South Africa, and over the years these rivers have either been dammed or the water consumption upstream has increased, leading to significantly reduced dry season flow in these rivers.

Surface water quality is often poor, especially during the dry season, and prone to carry diseases such as schistomiasis (Chaine, 1984). Even though the total dissolved solids concentration in groundwater is often much higher than that of the nearby surface water, where available, groundwater is generally less prone to contamination. Elevated fluoride concentrations in some groundwaters have been known to cause mottling of teeth but, once the sources have been identified, they can easily be avoided.

1.2 GROUNDWATER EXPLOITATION

Up until the early 1920's, groundwater was exploited primarily by hand digging of shallow holes in areas where water-bearing alluvium could be reached. As most of these dug holes were located in river beds, they were generally washed away during the ensuing wet season.

The early boreholes were drilled using cable tool rigs, by contractors who were mostly based in the Republic of South Africa (RSA). Typically, these boreholes were less than 50m deep and data on the yields was unreliable, as they were mostly based on short term bailing tests (Du Toit, 1928 and Morris, 1954).

Costs of drilling boreholes, and the characteristic "hit and miss" nature of the development process, was far beyond the reach of the average citizen living outside the urban areas, and hence development of deep groundwater sources was restricted to government institutions and a few relatively wealthy farmers. Proposals aimed at improving the standard of living of inhabitants of the Lowveld areas of Swaziland often failed to obtain financial approval, when it was found that they were based on utilization of groundwater.

Resistivity geophysical techniques, which have been successfully applied in the adjacent Republic of South Africa (Vegter and Ellis, 1968, Enslin, 1950 , van Wyk, 1961 and Kent and Enslin, 1962), have also occasionally been applied in Swaziland (Whittingham, 1967 and Martinelli & Associates, 1982$_{(b)}$). For a number of reasons, many of these studies experienced only limited success.

As part of a development project preceding the Swaziland Groundwater Survey Project, the Canadian International Development Agency (CIDA) assisted the Government of Swaziland (GoS) with training and equipping Rural Water Supply Board personnel for development of water supply systems, most of which had either spring or borehole sources (Piteau Associates, 1984 and Dakin et al, 1988). However, the boreholes were often not successful, due to a lack of knowledge of borehole siting techniques and proper drilling equipment in Swaziland.

Since the completion of the Groundwater Survey in 1991, the frequency of successful boreholes has significantly increased, with the result that there has been a heightened interest in the development of this resource (Piteau Associates Dec. 1992(b)).

1.3 HISTORY OF GROUNDWATER ASSESSMENTS IN SWAZILAND

Since the early 1930's, the Swaziland Department of Geological Surveys and Mines (DGSM), with the support of the British Government, has had an ongoing program of mapping geological formations and associated mineralized deposits in the country. In the latter phases of this work, some preliminary work on evaluating groundwater resources was carried out (Versey, 1977; Robins, 1978 and Robins, 1980). In the process of this mapping, many thermal springs were noted and records of the occasional borehole were examined for relevant geological information (Robins and Bath, 1979 and Hunter, 1968(b)).

As in many parts of the world, most boreholes were sited by property owners, water diviners, geophysicists and agricultural development officers, who did not have training in interpretation of complex geology and its relationship to groundwater. Consequently, many "dry" boreholes were drilled at considerable expense.

A number of consulting engineering firms, normally with offices in Swaziland, have been retained from time to time by local business enterprises and the Swaziland Water and Sewerage Board, to carry out investigations for groundwater supply (Gibb Hawkins & Partners 1982, 1983 and 1984; Martinelli & Associates 1982(a) and 1982(b); and Carl Bro Swaziland Ltd. 1982 and 1984). Judging by the general lack of production wells developed following these studies, they appear to have had only limited success.

The DGSM often assisted farmers, schools, medical clinics, etc. by surveying and locating borehole sites. Written reports on some of these surveys have survived (e.g. Morris 1954; Robins, 1977, Vilakati 1979; and Vilakati 1983). However, these endeavours were all conducted on an ad hoc basis, and records on the boreholes subsequently drilled are either incomplete, unreliable or unavailable.

No systematic records of boreholes (depths, yields, etc.) or groundwater chemistry were kept until a card catalogue system was initiated in 1975. However, even this system was not maintained. A brief overview report was prepared in 1987 by an officer seconded by the British Department of Overseas Development (Robins, 1978).

Over the period 1974 to 1979, the British Government seconded a hydrogeologist to assist with data collection. They also provided assistance to the DGSM for purchase of a cable tool drilling rig and survey equipment, which was used for drilling and development of exploratory and water supply boreholes.

A preliminary assessment of the use of satellite imagery as an aid to locating groundwater bearing zones was carried out in the United States (Clarke and Vilakati, 1977).

In 1981, the DGSM was given the responsibility of evaluating the Country's groundwater resources. Mr. A. Vilakati (one of DGSM's senior geologists) had already received training in hydrogeology; he helped convince the GoS that modern drilling rigs, specialized exploration equipment and trained staff were needed to enable the DGSM to help develop the groundwater resources of Swaziland. When approached for assistance, the Government of Canada agreed to help, and the concept of a groundwater survey program was conceived.

The first monitoring wells were established in 1986, when the Swaziland Groundwater Survey Project was initiated. Hence, there are very limited records of seasonal groundwater level changes and volumes of groundwater recharging the aquifers.

1.4 CIDA SPONSORED GROUNDWATER SURVEY PROGRAM

In 1984, the GoS and CIDA signed a Memorandum of Understanding, in which they agreed to jointly participate in carrying out a groundwater survey of Swaziland.

As part of this bilateral agreement, CIDA agreed to provide technical assistance, training of key personnel, and much of the equipment necessary to conduct the survey. The GoS agreed to provide trainees, office facilities, fuel for the drill rigs, accommodation and many other items. The GoS and CIDA both agreed that the overall Project objective was to "maximize the impact of groundwater exploitation upon the economic and social development of Swaziland."

More specifically, CIDA's role in the project was to:

"1) Establish the availability of groundwater resources and assess these resources in terms of quality and quantity;"

"2) Encourage the development of a National Water Authority including a Groundwater Branch in order to ensure rational use of all water resources including groundwater;"

"3) Increase the local capability of engaging in further groundwater exploration programmes and data analysis."

In September 1985, CIDA retained Piteau Associates Engineering Ltd. (PAEL) of North Vancouver, Canada, to act as the Project executing agency. Training and field work began in January 1986 and continued through to March 1991. This work included on-the-job training in geological mapping, geophysical surveying, drilling and testing boreholes, sampling and analyzing groundwater quality, data gathering, compilation in a computerized database, and preparation of hydrogeological maps and reports.

1.5 ACKNOWLEDGEMENTS

This report and the Groundwater Survey Program are the outcome of efforts of many individuals who worked on the international team. As such, it is impossible to name all involved. The study team would like to acknowledge the efforts of all individuals and organizations who contributed to the success of this Project, which culminated in the preparation of this report.

Aaron Vilakati, Director of the DGSM, while an active member of the study team, also had the foresight and persistence necessary to convince others that the Project was both worthwhile and viable. One of his strongest supporters was Ambrose Maseko (Under Secretary, Swaziland Ministry of Natural Resources, Land Utilization and Energy), who also played a very effective role in chairing the Project Steering Committee. Napoleon Ntezinde, Chief Engineer of the Swaziland Rural Water Supply Board, was a strong supporter and provided logistical support. Mr. Ntezinde was supported by Isaac Ngwenya.

The staff at DGSM willingly worked hard to collect and interpret the data. The capable efforts of Obed Ngwenya, Project Hydrogeologist, were much appreciated.

Technical information and support from all members of the Project Steering Committee, Rural Water Supply Board, Aqua Drilling Ltd., H_2O Drilling and Emanti Esive was very helpful.

Drillwell Enterprises Ltd. of Duncan, British Columbia, Canada, provided training of drilling personnel and logistical support throughout the entire Project. Dr. Ian Clark, of the University of Ottawa, Canada, provided assistance with analysis and interpretation of data on natural isotopes in water .

CIDA personnel located in Hull, Quebec; Pretoria, RSA; and Maseru, Lesotho, provided encouragement and logistical support to PAEL's team. The practical experience and constructive assistance of CIDA's hydrogeology review consultant, Mr. Bill Turner of Turner Groundwater Consultants, Victoria, British Columbia, is gratefully acknowledged. Mr. Mike Radman (USA Aid volunteer) and Jerry Wagner Watchell (WUSC, Canada) assisted in the office. PAEL's resident team was ably led by its field hydrogeologists, including Robert Matthews, Doug Bernard, Orest Tokarsky and Ted Negash. The assistance of PAEL's staff in Canada, notably Eileen Foster, Warren Newcomen and David Tiplady, was also an integral part of the Project and this report.

2. BACKGROUND INFORMATION ON SWAZILAND

2.1 LOCATION

Swaziland is one of the smallest African nations, with an area of 17,353 km^2 (see Figure 1). It is about one-half the size of Lesotho and one-fortieth the size of Botswana. Swaziland has a compact, rectangular shape, the maximum north-south distance being about 170 km, and east to west about 130 km. Most of the country lies between the 26th and 27th southern parallels, and the 31st and 32nd meridians. From Manzini, "the Hub of Swaziland", it is 397 km to Johannesburg and 622 km to Durban, both in South Africa (see Figure 2). The distance to Maputo in neighbouring Mozambique is 168 km, and to Maseru in Lesotho it is 619 km. Beitbridge, the nearest road access to Zimbabwe, is 685 km distant.

Swaziland is landlocked, bounded on the north, west and south by South Africa, and on the east by Mozambique. Being landlocked, Swaziland is inevitably dependent upon its neighbours, especially South Africa, for external trade and markets.

2.2 PHYSIOGRAPHY

Swaziland is a microcosm of southern Africa, encompassing within its small area four major geographical zones (see Figure 3): the mountainous Highveld (part of the Drakensberg Range) in the west; the rolling grasslands of the Middleveld in the centre; the bush savanna of the Lowveld; and, along the eastern margin of the country, the Lebombo Mountains. The higher elevations (above 1200m-asl) are along the western border and lower elevations (below 150m-asl) are found in the mid-eastern regions. The official division between the Middleveld and Highveld is at 1050m-asl elevation, and between the Lowveld and Middleveld is about 500m-asl. An east-west profile through the country is illustrated in Figure 4.

2.2.1 HIGHVELD

The Highveld (*Inkhangala*) covers about 29% of the country. It is a mountainous landscape that forms part of the Drakensberg Escarpment (Photo 1). The rock types here are large granite masses, and in the northwest also include some very old metamorphic rocks. Elevations generally range from 1,050 to 1,500m, although some peaks rise above this level, the two highest being Bulembu (1,862m) and Ngwenya (1,828m). Some of the rivers are deeply incised into this northwestern region, producing particularly striking relief in the vicinity of Piggs Peak.

2.2.2 MIDDLEVELD

The Middleveld (*Live*) lies between the Highveld and the Lowveld, and covers about 26% of Swaziland. Most of this region is underlain by granites and gneisses, and the differing hardness characteristics of these rocks produces a landscape of open plains and small hills (Photo 2). Elevation varies from between 500m and 1,050m.

2.2.3 LOWVELD

The Lowveld (*Lihlanze*) is the largest region, covering about 37% of Swaziland. Elevations range between about 150m and 500m, though within the region there are ranges of hills which are higher in elevation. The sedimentary rocks of the Karroo Supergroup underlie most of the area.

2.2.4 LEBOMBO HILLS

The fourth region is known as the Lebombo Hills (also part of the *Inkhangala*), which extend as a narrow belt along the eastern border of the country. It is the smallest of the regions, covering only about 8% of the country, and is basically an escarpment and plateau overlooking the Lowveld (Photo 4). The dramatic landscape is a product of the bedrock, which is composed of volcanic rocks at the top of the Karroo system of rocks. Elevations rise from the Lowveld to a maximum of 777m, then fall gradually towards the east (see Figures 4 and 5). The mountains are incised by the major rivers, producing deep gorges. Being higher, the climate is more equatable than that of the Lowveld.

2.3 POPULATION DISTRIBUTION

The estimated population of Swaziland is 800,000. There are several factors affecting population patterns in the rural areas of Swaziland, including the mosaic of freehold tenure land and Swazi Nation Land, as well as climate and the availability of arable land and water supplies.

Population density distribution in Swaziland is illustrated in Figure 6. While the population density of the country as a whole at the time of the 1976 Census was 28.5 persons per square kilometre (P/km^2), on individually tenured land it was only 11.5 P/km^2, and on Swazi Nation Land was as high as 36 P/km^2 (Goudie and Price Williams, 1983).

The densest population is in the Middleveld which, while only making up about one-quarter of the total land area, has over 40% of the population. Population densities in the Middleveld averaged 43 P/km^2, but exceeded 380 P/km^2 in many localized areas. In contrast, the Lowveld, which covers 37% of the total land area of the country, contains only 24% of the population. This could be because the Lowveld's low rainfall has an influence on crop production, although this is somewhat counterbalanced by the existence of more nutritious soils, and hence the better animal grazing lands. Perhaps of greater influence is that, until relatively recently, the Lowveld was rife with malaria and, to a lesser extent, tsetse fly.

At the other extreme, the Highveld region with its cool, humid climate and broken topography, has likewise discouraged population growth until the recent development of forestry and other industrial activities. The Highveld covers 29% of the surface area and contains 31.2% of the population. The Lebombo region, the smallest of the four, has 8% of the country's area, but only 4.6% of its population.

Recent political unrest in both the RSA and Mozambique has resulted in large influxes of refugees, most of whom have settled in camps established in the Lowveld area. Recent industrial development in Swaziland, partly as a consequence of increased trade with the RSA, has resulted in a reduced migration of skilled workers to the RSA.

The largest population centre is in the west central region, which includes Mbabane and Manzini (see Figure 6). This region also includes the Royal residences of Lobamba and Lozitha, the nucleus area of the Swazi Nation. Other concentrations of population include the mining town of Bulembu (asbestos) in the northwest Highveld, and the sugar estate towns of Mhlume, Big Bend and Simunye in the Lowveld.

The northern portion of the Mlumati Valley (north Swaziland) is another area of high population density, probably because of the fertile soils and relatively long history of settlement. There is also another concentration of population in the Nhlangano area (southwest Swaziland), a zone of fertile soil which was settled by the emerging Nation long before they moved to the central part of the country.

3. PHYSICAL RESOURCES

3.1 CLIMATE

The climate of Swaziland is sub-tropical, with Mbabane being about 300 km south of the Tropic of Capricorn. Traditionally, the summer trade winds can be relied upon to bring rainfall to Swaziland. However, over the last few years, summer rainfall has been considerably less than normal.

3.1.1 METEORIC DATA

Swaziland has a good network of long term meteorological stations dating back to the late nineteenth century, including Manzini and Siteki. About 60 rain gauges have been in operation for more than 20 years and, at 25 locations, maximum and minimum temperatures have been measured for 20 years or more. Less complete, but on the whole adequate, data are available for other climatic parameters such as wind velocity and humidity. Locations of most of the currently operating rainfall and meteorological stations are indicated on Figures 7 and 8, respectively. Graphical representation of the operating periods of the stations are presented in Figures 9 and 10.

Over the period 1984 to 1986, climate data was entered into a PC computer system for storage, processing and retrieval. Recently, the system was upgraded again to make it even more user-friendly and compatible with World Meteorological Service standards. The Groundwater Survey Project made extensive use of this data.

A summary of monthly average rainfall and temperature data for selected long term stations, distributed throughout the four main physiographic regions, is presented in Tables Ia and Ib, respectively. Additional meteorological information is presented in graphical and tabulated form in Appendix C. Average monthly rainfall, temperature and evapotranspiration trends are presented in Figures 11 and 12.

3.1.2 RAINFALL

The relationship between relief and rainfall is strong. As illustrated in Figure 4, for every 100m increase in elevation, there is an increase of about 90mm in mean annual rainfall.

The Lowveld area, which depends only on convective air currents for its precipitation, receives between 600 to 800mm of annual rainfall (see Figure 13). The Highveld is the coolest and wettest area of the country, with orographic lifting of warm, moist air adding its effect to the convective activity. It receives an average of between 1,000 and 1,300mm annually over most of the area, and as much as 1,800mm in the Bulembu-Piggs Peak area.

The rainy season coincides with the onset of warmer weather and can start as early as September. Typically, it continues through to March, but this does not preclude rainfall occurring at virtually any time of the year. In spring and autumn, cold fronts with polar air masses occasionally lift warm tropical air, producing rain and cold weather.

Rainfall in Swaziland tends to come in bursts during intense electrical storms, which rarely persist for more than a few days at a time. This applies particularly to stations in the Lowveld areas, and is reflected in the statistics for rain days presented in Appendix A. For example, the average number of rain days per year in Big Bend (in the Lowveld) is about 38, and at Bulembu (in the Highveld) it is 126. Many stations did not receive any rainfall during the 1962-63 or 1963-64 water years, due to the severe drought experienced in the country.

Stations with records extending back to the early 1920's confirm that there has been at least one extended period of consistently low annual rainfall since that time. This is graphically illustrated in Figure 14, which shows the cumulated sum of deviations from the mean monthly rainfall (cusum) for the Siteki station. The periods of persistently low rainfall are those where the cumulative deviation graph has a negative slope (e.g. the period 1925 to 1935). Similar trends are shown on other cusum diagrams included in Appendix C.

As illustrated in Figures 11 and 12, maximum monthly rainfalls reach about 850mm, recorded during March at the Mbabane station. While the Bulembu station receives more annual rainfall than Mbabane, the monthly extremes appear to be less. These figures also illustrate the high degree of variation of monthly rainfall.

The lowest monthly average rainfall was 9mm recorded during August at the Big Bend station, located in the Lowveld. The highest was about 295mm, recorded at Bulembu in the Highveld during February (see Table Ia and Tables C1 to C7 in Appendix C).

Twenty-four hour rainfall intensity is only available for the 20 meteorological stations indicated on Figure 8. Data for selected long term stations is provided in the tables in Appendix C. These records show that many stations have records of events where 24-hour rainfall exceeded 200mm. The maximum recorded was 290.6mm at Bulembu in 1939. The three hurricanes of this century occurred in 1925, 1966 and January 1984. The latter, Cyclone Demonia (Goudie and Price Williams 1984), caused widespread damage throughout the country.

3.1.3 TEMPERATURE

Daily extremes range from -6.7°C at Big Bend up to 47.4°C at Lavumisa. The mean monthly temperatures range from about 12.1°C in Mbabane up to about 27.6°C during January in Big Bend (see Table 1b). Mean annual temperatures range from 16.7°C in Mbabane to 22.6°C in Big Bend.

Air temperatures are of hydrogeological interest, as groundwater temperatures are typically within a few degrees of the mean annual air temperature. These are shown in isohyetal form on Figure 15, and suggest that groundwater temperatures should range from about 18°C in the Highveld up to 22°C in the Lowveld. As indicated in Section 6.5, the average groundwater temperature in any given area has generally been found to be about 2°C higher than the mean annual air temperature.

3.1.4 EVAPORATION

Class A pan evaporation data is available for ten stations, of which six have at least ten years of data and three have data for more than twenty years (see Figure 10). Stations are generally in the Lowveld and Middleveld, where the more important agricultural areas are located.

Loss of water from soil, crops, streams and lakes as a result of evaporation is more significant at lower elevations because of clearer skies (Murdoch and Andriesse, 1964). Winter water evaporation losses are increased by the combination of clear skies and dry air masses of continental origin. Water losses for a wide range of plant associations have been surveyed in southern Africa, and this information has been used in the estimate of transpiration losses for a number of hydrological studies (Henrici, 1940).

Annual evaporation is lowest in the higher elevations (i.e. 1,300mm at Mbabane and 1,711mm at Matsapha), and is highest in the Lowveld (2,150mm at Mananga). Monthly evaporation does not vary significantly throughout the year, typically ranging between 150mm to 200mm per month (see Figure 12 and tables in Appendix C).

Potential evapotranspiration (PET) for the Big Bend (formerly called Wisselrode) Station (Murdoch and Andriesse, 1964) was estimated using four different methods. Calculated PET's, methods and factors used are, respectively, 1,212mm (Thornthwaite, 1948); 1,273mm (Penman, 1954; f = 0.8); 1,295mm (Walker, 1957; f = 0.8); and 1,457mm (Blaney 1955; k = 0.8). These PET data compared reasonably well with the actual 1984 pan evaporation of 1,525mm. Measured annual evaporation for 1980 and 1988 ranged between 936 and 3,156mm, and averaged 2,074mm. Based on these results, it appears that calculated potential evapotranspiration is about 63% of the average measured evaporation data from this time period.

3.1.5 DROUGHT HAZARD

Swaziland experiences prolonged periods of drought during the winter months when there is little or no rainfall. Even in the summer rainy months, consistent rainfall cannot be expected. Thus, many parts of the country often do not receive sufficiently persistent rainfall to accumulate enough moisture in the soil for growing crops.

The annual rainfall required to grow maize without irrigation in Swaziland is about 630mm, and many areas frequently do not receive this amount. Drought probability maps for precipitation amounts on either side of this critical value are presented in Figure 16. For much of the Lowveld, it is likely that in six summers out of ten (i.e. 60 %) rainfall will be less than 508mm, and eight summers out of ten (80%) will receive less than 725mm. For the Middleveld and Highveld, the chances of drought are 20% and less than 1%, respectively. Land use capability based on rainfall is shown in Figure 17.

3.2 VEGETATION AND AGRICULTURE

Agriculture is the backbone of the Swaziland economy, and in 1984 it directly represented about 23% of GNP and generated about 40% of export returns. Agriculture also employs about 75% of the indigenous wage earners. Since 1984, crop production has stabilized while manufacturing production has increased substantially. In approximately one-third of the country, irrigation is essential for intensive agriculture (see Figure 17).

3.2.1 HIGHVELD

The vegetation of the Highveld is today dominated by extensive man-made forests of pines, gums and wattles. All of these are of foreign origin, being introduced commercially from outside Africa during the last few decades (Photo 1). They tend to obscure the natural vegetation which, where present, is of two types. The more exposed areas are covered with sour mountain grassland, while indigenous trees typical of African highland areas (see Figure 18) are restricted to protected ravines and boulder fields which are free from winter frosts. Rainfall throughout this area is very high, and leads to several mineral deficiencies in the soil. The resulting acidic conditions produce an unpalatable grassland unsuitable for intensive grazing, and the cultivation of crops is not possible without replacing the leached minerals with expensive fertilizers.

3.2.2 MIDDLEVELD

The Middleveld, like many parts of tropical and sub-tropical Africa, is subject to a long dry season during the winter which promotes a vegetation normally called "savanna". The savanna is characterized by tall grasslands, which have varying densities of trees. In the Middleveld, the savanna changes from west to east according to the amount of rainfall. The westerly areas tend to be more heavily wooded, especially near rivers where moisture is greater. The eastern areas have fewer trees, and those present are species which can withstand drought.

Long grass is the predominant vegetation type in the Middleveld, and hence is important agriculturally. Agriculture, together with the undulating nature of the terrain and a readily available surface water supply, combined to make this the most densely populated rural region of the country.

The entire region, with the exception of some of the most eastward parts, provides a fertile environment suitable for development of mixed agriculture (Photo 2). As a consequence, much of the original vegetation has been removed and foreign cash crops have been introduced. This is particularly evident in the heavily developed Malkerns Valley.

3.2.3 LOWVELD

In the Lowveld, more severe and prolonged winter drought and higher overall temperatures have promoted a drier savanna grassland. These severe climatic conditions are enhanced by the effect of the rain shadow caused by the adjacent Lebombo Mountains. The vegetation of the Lowveld consists of a mosaic of sweet grassland with scattered deciduous and drought resistant trees, such as the many species of thorn trees (e.g. *Acacias, Mkhaya, Siftwetfwe*, etc.). *Inkhanyakudze* trees (a member of the Acacia family) are commonly found in low lying areas, and are considered a reliable indicator of the presence of a shallow groundwater table.

Under natural conditions, these lands have always been capable of supporting large herds of animals. The grasses are highly nutritious because minerals in the Lowveld soils are not removed by high rainfall, and indeed actually rise to the surface through high temperatures to assist plant growth. However, unnaturally high stocking levels can lead to total removal of grasses, upsetting the equilibrium of the area. In three parts of the Lowveld, the natural vegetation has been totally removed, and irrigation has been introduced to enable sugar cane to be grown in an area in which it could not naturally occur.

3.2.4 LEBOMBO

This is a fairly narrow zone. Although it lies to the east of the dry Lowveld, it attracts a higher rainfall because of its greater altitude and its proximity to the Indian Ocean. The west-facing steep slopes, like the adjacent Lowveld, are in a rain shadow and therefore are not capable of supporting a great density of vegetation. Conversely, the wetter east facing slopes are often heavily wooded. Some of the trees are similar to those in the Lowveld, but others are rare and originate from the maritime plains of Mozambique. Notable features of this area are the steep ravines in and adjacent to the river gorges. They support a large number of tree species, including some of the rarest plants on earth.

3.3 SURFACE WATER

3.3.1 WATER RESOURCES

Despite being located in the generally arid to sub-tropical region of southern Africa, Swaziland has long been regarded as one of the best watered areas of the region, because it is traversed by several large rivers (see Figure 19). The combined mean natural discharge for all rivers leaving the country is about 144 cubic metres per second (m^3/s), or some 4,500 million cubic metres per year (Mm^3/y). A little more than half of this flow is derived from precipitation in Swaziland (2,640 Mm^3/y). Increasing extraction of water, both in South Africa where some of the rivers rise, and in Swaziland through which they flow, is reducing the overall amount in the rivers themselves. Current consumptive water usage in Swaziland is estimated at 1,500 Mm^3/y (47.4 m^3/s) (MacDonald & Partners, 1990), which represents about 33% of that leaving the country.

Nearly all the streams and rivers in the Highveld are perennial, due to the relatively high rainfall and presence of permeable water-bearing strata capable of storing and then releasing water to the rivers. Other than the larger through-flowing rivers, water courses in the Lowveld tend to flow only after heavy local rainstorms. Even in those rivers that flow throughout the year, discharge is extremely variable (see Figure 20) because of the strongly seasonal nature of rainfall; hence, the need to store water and to develop groundwater resources. Maximum discharge occurs in the late summer, namely in January, February and March, and minimum flows generally occur in July or August.

3.3.2 DRAINAGE BASINS

The larger rivers flow from the Highveld in an eastward direction towards the Indian Ocean. The principal rivers are the Mlumati, Komati, Mbuluzi, Lusutfu and the Ngwavuma. A summary of data on these rivers, plus two small but significant basins (the Mnzimnyame and Pongola), is provided in a table included on Figure 19. Four of these river basins are located entirely within Swaziland. Flows for the Lusushwana, Ngwempisi and the Mkhondvo Rivers have been incorporated into the Lusutfu flows shown on Figure 19.

The average annual runoff for all rivers represents 150mm of annual runoff at the downstream border of Swaziland, or about 17% of the average annual total rainfall (882mm) on the catchment area (Swaziland and South Africa). This is relatively high when compared with 8% of rainfall on all South African river catchment basins.

Estimated runoff per unit area for basins principally draining the Highveld areas is significantly greater than that of the rivers which are principally draining the Lowveld. For example, the Komati River, above the Vergelegen gauging station (No. 26 on Figure 21) has 329mm of annual runoff (20% of rainfall), while the Mbuluzi in its Lowveld stretch (Station 20) discharges about 25mm of runoff, representing about 4% of rainfall.

3.3.3 SURFACE WATER QUALITY

A review of the limited number of available inorganic water quality analyses shows that total dissolved solids (TDS) in major rivers is generally less than 150 mg/L. Even lower TDS values (less than 30 mg/L) are typical of small creeks draining the granitic terrain of the Highveld.

In spite of the relatively low TDS of waters in the Lowveld rivers, surface waters are generally not safe for human consumption due to potential high coliform counts and the presence of bilharzia blood-fluke, which is transmitted by a fresh water snail (Chaine, 1984).

4. GEOLOGY AND SOILS

4.1 GEOLOGY

4.1.1 STRATIGRAPHY

The largest part of Swaziland is directly underlain by Ancient granites and gneisses which are of Archean (Pre-Cambrian) age and are on the eastern edge of the Kaapvaal craton. These rocks, together with ancient metamorphic rocks of the Swaziland and Pongola Supergroups, occupy the highland area in the western and central parts of the country. In the east are sedimentary and volcanic rocks of the Karroo Supergroup, which date from the Permian to the Jurassic Epoch. These younger rocks, comprising the Lowveld and Lebombo areas, lie on the eastern flank of the craton (see Figure 22). A stratigraphic column is provided in Table II, and more information on geology is provided in Appendix D.

Swaziland is distinguished geologically for having some of the oldest sedimentary rocks in the world, namely the Swaziland Supergroup rocks. The oldest of these, said to be about 3,540 million years (My) old is known as the Dwalile Metamorphic Suite consisting of volcanics and sediments (Table II). Above these are the Fig-Tree and Moodies Groups, which contain shales, cherts and quartzites. Also amongst the Fig-Tree are banded ironstones, some of which have been exploited for iron ore in the northwestern part of the country. These ironstones are more resistant to erosion and form the topographic ridges, while the intervening shales are softer and tend to form the valleys. This explains the relatively rugged relief characteristics of the Greenstone Belt in the northwest area of the country.

The principal rocks in the Middleveld are ancient granites and gneisses. These are all Archean age rocks, being more than 2,000 My old. The varying chemical composition of these rocks has led to a difference in bedrock weathering, and subsequent differential erosion has controlled the topography of the Middleveld.

The Karroo Supergroup rocks were formed over a 100 My time span in a terrestrial environment. There is no evidence of marine sedimentation in the Swaziland Karroo. However, Wilson (1982) suggested that claystones with boulders and pebbles, found near Nhlangano in southwest Swaziland, were deposited in a prodeltaic environment, involving reworking of glacial deposits.

Starting at the base of the Karroo succession (see Table II), there are glacial sediments (tillites) formed when southern Africa lay over the South Pole some 300 My ago. Overlying these are various shales, siltstones and sandstones, some of which include coal measures that are presently mined. The uppermost rocks in the succession are volcanic basalts and rhyolites, which were poured over the land surface about 200 My ago. These Karroo rocks are intruded by numerous dolerite dykes and sills.

4.1.2 STRUCTURE

All rocks in Swaziland's stratigraphic succession have been affected by faulting and folding to some degree. Most faults trend in north-south to north-northeasterly or north-northwesterly direction, but a wide range of directions are observed (see Figure 23).

The nature of the faulting varies. High angle thrust faults are common in the Greenstone Belt, while block faulting predominates in other areas.

Two major north-south trending mylonite shear zones affecting Archean granites and gneisses and Mozaan Group sediments are present in central Swaziland (see enclosed hydrogeology map). These zones grade into narrow, often bifurcating, shears or faults at their extremities. The dip of the eastern zone is eastwards at 65 to 75°. The western zone also has an eastward dip, but at shallower angles (35 to 55°). The age of this shearing is apparently post-Mswati granite and pre-Karroo (Hunter, 1961). Much evidence is cited of fault action, with the rocks of the shear zones being dense, fine-grained, and often streaky, strained, and multi-coloured.

For a more detailed description of the Swaziland geological units, see Appendix D.

4.2 SOILS

Soil is defined by pedologists as "that earth material which has been so modified and acted upon by physical, chemical and biological agents that it will support rooted plants". In Swaziland, the chemical processes are dominant, as the climate is warm and there is a sufficient rainfall to activate these processes.

Plots of mean annual temperature versus mean annual precipitation are useful for assessing the degree of weathering. These parameters for four of the major climate stations, representing the four principal physiographic zones, are plotted on Figure 24. This figure shows that the chemical weathering is moderate to strong in the Highveld areas (e.g. Mbabane), moderate in the Middleveld (e.g. Hlatikulu), and potentially moderate to very slight in the drier parts of the Lowveld (e.g. Lavumisa).

Other factors in the development of soil include resistance of rock minerals to either chemical or physical processes, groundwater flow rates, heterogeneity of rock, presence of chemical buffers (e.g. calcite), etc.

In their role as raw materials for soil formation, the rocks of Swaziland fall into three broad groups - acid, basic, and intermediate (or mixed acid and basic).

Coarse granite, porphyritic granite and granophyre bosses, Mozaan quartzite, Lower Ecca grit, Molteno sandstone and Lebombo rhyolite are the chief examples of acid geological formations, with inert quartz the predominant mineral (Murdoch, 1972). Soils developed on these rocks are usually shallow, not infrequently absent and, where a solum has developed, it is nearly always sandy (Photo 5).

By contrast, basic and ultrabasic rocks such as Usushwana gabbro, Sabie River basalt and the dolerites and other mafic intrusions of various ages will, on weathering, have a tendency to develop soils with a high clay content. This is especially true for basalt, which weathers to greater depths than those rocks with acid parent material at topographically and climatically analogous sites.

Relationships between depth of weathering (roughly analogous to the depth of casing installed in a borehole), rock types and physiographic regions are illustrated on the bottom half of Figure 24. This shows that weathering is generally deepest in the Highveld region. However, this diagram also shows that depth of weathering is relatively variable when compared to rock type. In particular, sedimentary rocks tend to show greater weathering than their chemical compositions would suggest.

Over the remainder of the country, geologic units are either truly "intermediate" (e.g. most granodiorite and andesite, some gneiss, and occasional slightly calcareous Upper Ecca sandstone), or more frequently have veins and lenses set within a matrix of different mineral composition. These mineral compositions are so intricately and inextricably combined that when geomorphic and soil-forming processes are initiated, the whole mass behaves as a single polygenetic parent material. The most common admixture is of basic intrusives within a siliceous body, such as:

i) Post Swaziland metamorphics with acid gneiss.

ii) Epidiorite occupying joint planes in granite.

iii) Dolerite sills that have penetrated Karroo sediments.

Weathering of these composite rocks is hastened by their internal heterogeneity. The deepest soils in Swaziland have been fashioned from intermediate parent material, including both alluvium and colluvium. The resultant soils are mainly of medium mixture, with a range from sand to loam to sandy clay.

Comparing the three rock groups, outcrops are most common in places where parent material is mainly acidic (43% of the total area, compared with 17% and 16% for intermediate and basic parent material zones, respectively). Residual and colluvial soil are most extensive where the source rock is basic (80% of the total area). Alluvium, particularly along major rivers, usually originates from fragments of disparate rocks and soil wash, which have blended from mixed parent materials.

The Middleveld and Lowveld subregions are more distinct geologically than physiographically. The Lowveld is readily divisible into an Eastern subregion (EL), where the parent material is overwhelmingly basic, and a rather larger Western subregion (WL), with more varied rocks and soils. Slightly more than half the WL is associated with acid rock. The Middleveld is split less decisively into a discontinuous Upper subregion (UM) with much intermediate parent material mapped in two segments, and a Lower subregion (LM) which abuts on Highveld mountains in the Assegai-Ngwempisi basins and above Kubuta. The lower Middleveld has a higher proportion of acid rocks than any other part of the country.

Soil types in Swaziland can be subdivided into nine broad categories, ranging from raw mineral soils to halomorphic (salty) soils. These categories and their distribution are listed and plotted on Figure 25. The relationship between topography (and indirectly climate) is very obvious on this figure, with all hydromorphic soils being located in the Lowveld area.

The relationship between permeability, leached chemistry and topographic position for the Swaziland soils is shown on Figure 26. This figure shows that the more acidic the soil (i.e. from granitic areas), the more permeable it is likely to be unless mineral salts are not well leached out, and hence the soil tends towards a less permeable, halomorphic soil. The presence of many shallow springs in the Highveld and Middleveld areas of Swaziland can be explained by the relationships shown in this figure. For example, ferralitic soils in steeper terrain would be expected to freely transmit shallow groundwater flow. As indicated on Figure 25, there are extensive areas of this soil unit (Unit H) in the northeastern sector of the country.

5. HYDROGEOLOGY

5.1 HYDROGEOLOGIC OVERVIEW

There are very few thick sequences of permeable geologic units, either consolidated or unconsolidated, in Swaziland and hence secondary permeability is of prime importance for groundwater flow and storage. As indicated in the previous chapter, massive bedrock is often at or very close to the ground surface, except in some of the valley bottoms. Groundwater flows in zones of deep, continuous weathered bedrock are rare and restricted primarily to the Ezulwini, Malkerns and Manzini areas. In other areas, groundwater flow is predominantly through either fractured and jointed bedrock, or shallow, discontinuous weathered zones. An illustration of a typical aquifer and groundwater flow system in the mountainous areas of Swaziland is presented in Figure 27. More details on these concepts are provided in the following sections, and in Chapter 6.

5.2 HYDROGEOLOGIC UNIT DESIGNATION

There are no aerially extensive aquifers in Swaziland, and hence mapping hydrogeologic units for the purpose of the Groundwater Survey is problematic. After a number of attempts, a system that simply defines all major geological units as hydrogeologic units and provides a means of identifying sub-categories of these units, was adopted. A series of two-letter codes was established to identify these units and their sub-categories. For example, the Nhlangano Gneiss has been designated as hydrogeologic unit GL. However, where there is definite evidence that there is an extensive water-bearing fault or fracture (FZ) within the unit, then the unit is designated GL/FZ. If portions of this unit had hydrogeologically significant features such as weathering (WE), then the unit would be further sub-divided and designated unit GL/FZ/WE.

The principal geologic units and their corresponding hydrogeologic unit designations are indicated in Table II. The distribution of these units is presented on the 1:250,000 scale hydrogeology map included in this report. As indicated in a companion report (PAEL, $1992_{(b)}$), data was entered into a computer database for analysis. Pertinent information and statistics on these units based on the results of the Groundwater Survey are summarized in Tables III to VI, and presented in graphical form in Figures 29 to 40. Information on groundwater quality is provided in Chapter 7.

In Section 5.4 onwards, highlights of the more significant hydrogeologic units are presented and discussed under their general rock type, i.e. granitic, metamorphic, volcanic or sedimentary.

5.3 SOURCES OF DATA AND STATISTICS

Information on boreholes, springs and hydrogeological information was collected from a variety of sources, including old reports, personal interviews, drillers' logs and from information collected as part of Project activities. The latter source included detailed information on 395 exploratory boreholes. The locations of the Project boreholes are indicated on Figure 28, and the magnitude of the borehole yields is shown on Figure 29.

As of March 1991, there were records of 1,653 boreholes in Swaziland; 946 had data on yields and 1,048 had depth information (see Tables IV and V). Less than 500 had lithologic information, with most of these being Project boreholes. Locations of all boreholes with yield information are indicated on the 1:250,000 scale hydrogeology map.

Short term blown yields ranged up to 20 L/s and averaged 1.36 L/s (see Figure 30), with the yield distribution heavily skewed towards the lower yield values. About 16% (151) of all boreholes with yield information were "dry", defined as having a yield of less than 0.01 L/s (1 gpm). The higher yields are almost all from boreholes penetrating major regional faults.

Borehole depths ranged up to about 305m and averaged 58.8m (see Figure 30). The population distribution for these depths was almost Gauss normal. In general, lower borehole yields are expected in rock ridge areas, where selective erosion and degree of weathering and fracturing of bedrock is less than in adjacent valleys. However, plots of borehole yields versus elevation (see Figure 31) were assessed and indicate that there is no obvious relationship between short term yields and elevation.

There are 324 located and documented springs in Swaziland, and it is estimated that this may only represent about half of all springs with yields greater than 1 L/s. Statistics on discharges of 276 of these springs are summarized on Table VI.

5.4 GRANITIC UNITS

5.4.1 GRANITES (G3, G5 AND GR)

Three granite hydrogeologic units have been designated, and these are G3, G5 and GR. Their chronologic significances are indicated in Table II and statistics on boreholes drilled into these hydrogeologic units are listed in Tables III and IV. Considerable information is available on hydrogeology of granitic areas in Swaziland, which for many years have been favoured targets for exploration. For example, Hall (1918) noted that favourable hydrographic conditions were present in the granitic terrain of the Komati River basin. This was a result of rainfall penetrating into weathered granite bedrock (unit G3/WE), and infiltrating down to the water table aquifers, with the resulting temporary storage causing reduced wet season surface water runoff.

Topographically, the granite plutons are readily identifiable as being resistant to erosion and tend to form the high ground (Photos 6 and 7). Springs (123 records) have been noted in many places in granitic terrain. Contact springs, which are often associated with dykes and crush zones, occur frequently in these hydrogeologic units. Data on springs located in granites are summarized in Table VI.

There are records of 302 boreholes in all the granite hydrogeologic units. Borehole depths ranged up to 191m, and averaged 52m (see Table III). Of these boreholes, 141 have records of blown yields, which ranged up to 8 L/s and averaged 1.15 L/s. Eighteen percent (26) of these boreholes yielded less than 0.01 L/s (effectively "dry") as compared to 15.3% for all units in Swaziland. These statistics also indicated that 20%, 23% and 10% of the boreholes in units G3, G5 and GR, respectively, were "dry". The GR unit had the highest average yield (1.42 L/s) and G5 the lowest (0.86 L/s) of the three units (see Table IV).

5.4.1.1 Lochiel Granites (G3)

The Lochiel Granite hydrogeologic unit is distributed throughout much of the northwest Highveld region and is intruded by the Usushwana Complex (UC), Mswati (G5) granite and by numerous northeast, southwest and northwest-southeast trending dykes of dolerite and diorite. Small isolated remnants of the underlying gneiss and associated amphibolites are scattered throughout the unit.

There are records of 157 boreholes in the G3 unit. Eighty of the boreholes have records of blown yields, ranging up to 7.0 L/s and averaging 1.17 L/s. Twenty percent (16) of these were dry. A histogram of the yield data is presented in Figure 32. Based on data available, the highest yielding borehole in this unit is K28-02, which is located in the northern part of the country. The principal water strike in this borehole was in a fracture zone, located at a depth of 122m.

The depth distribution for boreholes in the G3 unit is almost normal (see Figure 34), indicating that the boreholes encountered randomly positioned fractures in bedrock sufficient to produce the desired yield when drilling was terminated. Depths ranged up to 137m and averaged 59.3m.

Massive G3 is not water-bearing, and the better yields are all found at contacts between geological units and in fault or fracture zones. Further evidence of the relatively high permeability and water transmitting capacity of these zones is the presence of many springs in the sides of valleys, adjacent to where dykes have daylighted. Comments on the productivity of the more common water-bearing zones are provided in the following.

G3/Dolerite Intrusive Contacts (G3/DO)

Dolerite dykes and sills are the youngest intrusive body in the G3 hydrogeologic unit. While the G3/dolerite contact zones with dolerite dykes (unit G3/DO) are often weathered and productive, statistics show that as many as 36% (five) of the boreholes known to be located at these contacts were "dry". The high failure rate at these contacts is attributed to the fact that the contact is often very sharp, with few voids, open cracks or weathered zones in the hardened recrystallized granite. Also, in order to ensure the highest yield possible, boreholes must be very carefully sited to ensure that a weathered contact zone is intersected a few tens of metres below the prevailing water table. Similar observations have also been noted in Transvaal (Enslin, 1961) and in Northern Natal (Van Wyk, 1963).

G3/Gneiss Contacts

The G3 unit is younger than the gneisses and the contacts are typically diffuse. These contacts can also be relatively productive. For example, a borehole (K28-01) near the Ebuhleni Royal Residence was positioned at the contact between G3 and a small outlier of the Ngwane Gneiss unit (GW). The borehole penetrated alternating G3 and GW (see log of this borehole in Appendix E), and had a blown yield of 3.3 L/s. Hence, it can be concluded that properly located boreholes in the G3/Gneiss contact zone can produce significant quantities of water.

G3/Diabase Contacts

Diabase intrusions into G3 are common in most areas. Diabase dykes are typically oriented northwest to southeast, and potentially provide productive sources for properly positioned boreholes.

Diabase intrusions often disturb the country rock, and in some areas the nearby fractures in the G3 unit form good water-bearing zones. For example, borehole T14-01, located about 20 km north of Mbabane, was drilled close to (but not into) a diabase dyke and had a yield of 5 L/s. This 67m deep borehole had a first water strike at a depth of 15.3m, just below the clay overburden, and the principal water strike was at 41m. Based on the results of the constant rate aquifer pump test, it is believed that this unit is hydraulically connected to the dyke. These productive zones are often located in the bottom of valleys.

Regional Fault and Fracture Zones in G3 Granite (G3/FZ)

When a borehole encounters a regional fault in this unit (G3/FZ), the yields are often very high. For example, blown yields of 13.3 L/s and 10 L/s, respectively, were obtained from boreholes H22-01 and AD12-01. These two boreholes were located in northeast-southwest trending faults (see Figure 23 for a general location and the 1:250,000 scale hydrogeology map for a more specific location). The G3 fault zones are typically very weathered and a quartz sand often flows into the borehole. This suggests that groundwater has been flowing relatively rapidly along the faults for a long time, and consequently localized weathering of micaceous and kaolinitic minerals in the granite is well advanced. Before these boreholes can be used as production wells, it is generally necessary to insert slotted casing liner into the borehole to stabilize the weathered rock walls within the productive fault zone. More information on the hydrogeology of regional fault zones is provided in Section 5.9.2.

5.4.1.2 Mswati Granites (G5)

These coarse-grained granites are the youngest granites in Swaziland (Hunter, 1961) and were emplaced in several discrete plutons (Photos 6 and 7). This unit characteristically has many feldspar megacrysts and aplite (acidic) dyke intrusions. With the exception of the Sinceni Pluton, basic intrusions are rare in G5 bedrock. This pluton has been invaded by many pegmatite dykes, some of which are hundreds of metres wide.

Mswati granites weather deeper and more easily than most of the granites in Swaziland, leaving residues of quartz sand and red-brown clay (Photo 8).

In many areas, the surface water drainage patterns are very rectilinear (e.g. the Mbabane pluton). The orientation of valleys is thought to be fracture controlled, and these fractures are the source of many springs found in this hydrogeologic unit.

While the G5 granites are relatively permeable, the permeable zones are typically thin, particularly in the upland areas, and thicken towards the valleys. The talus deposits around the perimeter of the G5 plutons locally form small groundwater storage reservoirs (see Figure 27 and Photo 6); for example, on the eastern side of the Ezulwini Valley and on the eastern slopes of the Ngwempisi Pluton (Ntondozi Hill).

There are records of 94 boreholes in the G5 unit, of which 31 have records of blown yields. These yields range up to 5 L/s and average 0.86 L/s, with 23% (seven) of the boreholes being dry. The highest yielding borehole in this hydrogeologic unit (AP35-51) is located in the lower Middleveld area, not far from the Duze School.

5.4.1.3 Other Granites (GR)

The Other Granites include coarse grained granites of the Hlatikulu, Kwetta and Mtombe Plutons. These hydrogeologic units are located in the southern Middleveld area of Swaziland.

Hlatikulu granite is very similar to Lochiel granite, and the Mtombe granite covers a very small area. Kwetta granite typically has numerous dolerite sills and megacrysts. These sills often cap the hills and could potentially reduce groundwater recharge. They may also act as aquitards, forming perched water tables. However, there are insufficient boreholes in this unit to provide confirmation of these theories.

There are records of 51 boreholes in the GR unit, of which 30 have records of blown yields. These yields range up to 5 L/s and average 1.42 L/s, with 10% (three) of the boreholes being dry. The highest yielding borehole (BK25-51) is located in the Lowveld area. However, as this is not a Project borehole, it was not possible to confirm the lithology and yield. The highest yielding Project borehole (BO26-01, 1.3 L/s) produced most of its yield from weathered granite above a depth of 37m.

5.4.2 GRANODIORITES (GD AND GM)

Two granodiorite hydrogeologic units have been designated, and these are GD and GM. These units are located primarily in the Middleveld and upper Lowveld areas. Their chronologic significance is indicated in Table II, and statistics on the boreholes drilled in these units are listed in Tables III and IV. The majority of the drilling information was obtained from the GD hydrogeologic unit, which is summarized and discussed in the following subsection.

Springs are a relatively common occurrence in this unit (22 records). Data on these springs are contained in Table VI.

5.4.2.1 Usutu Granodiorite (GD)

The Usutu Granodiorite hydrogeologic unit is present at many relatively scattered locations throughout the central and south-central sectors of the country. Residuals of serpentinite, amphibolite and pegmatite can be found scattered throughout the unit. Dolerite, gabbro and diorite intrusions (both dykes and sills) are relatively common throughout this unit, and generally provide productive water sources. Zones of deep weathering and contacts between GD and amphibolite are good water-bearing zones.

There are records of 183 boreholes penetrating the GD unit. The average depth of boreholes with depth information in this unit was 48.5m (see Figure 33), with the depth distribution being skewed towards shallower boreholes. Records of 97 boreholes with blown yield information are available and range up to 20 L/s, averaging 1.61 L/s (see Figure 32). Over half of the water-bearing boreholes penetrated one or more dolerite dykes, and many intersected fault or fracture zones. The highest yielding boreholes (AC23-02 and AE24-01) both yielded about 20 L/s. Borehole AC23-02 is located on a regional fault, while AE24-01 is located relatively close to a large dolerite sill, a unit boundary (with a gneiss unit (GW)), and is in deeply weathered rocks.

In the drier Lowveld areas, where weathering has not been as significant in this unit, borehole yields are generally low. Some comments on the various water-bearing zones are included in the following.

Contacts with Xenolith Bodies (GD\AM and GD\SE)

Boreholes located in or near the granodiorite-amphibolite and serpentinite contacts have almost always produced significant short term (blown) yields. However, due to the limited areal extent of these zones, the long term sustainability of the borehole yields needs to be carefully evaluated for each location.

Intrusion Contacts (GD\DO)

Boreholes located close to or intersecting dolerite (DO) and other intrusive contacts, such as diorite, have been successful in this unit. For example, borehole AI20-06, located at the University of Swaziland campus, penetrated a highly weathered granodiorite, but did not produce significant amounts of water until a dolerite dyke was intersected at a depth 38.5m below ground. After intersecting the dyke, the borehole produced 6.7 L/s.

Weathered Granodiorite (GD\WE)

Usutu Granodiorites tend to weather deeply. A typical weathering profile is shown in Figure 34. In the steeper hill slopes, the weathering products are typically eroded away, leaving either bare rock or dongas. Extensive and potentially productive water table aquifers are often found in the valley floors, where the well leached GD rock residuals (mostly quartz sand) have been left intact. For example, four boreholes drilled for the Project (AL15-02, AK15-01, AM14-01 and AL15-01) penetrated weathered GD in the Malkerns area and yielded 1.5, 4.0, 6.0 and 6.7 L/s, respectively.

While there are numerous boreholes in the GD/WE areas of Malkerns, Ezulwini and Matsapha, most were drilled with a cable tool rig and have barely penetrated the water table. Project boreholes AI20-01 and AI20-05 drilled on the University of Swaziland campus had yields of 1.5 and 2.0 L/s, respectively. However, before these boreholes could be used as production wells, they required insertion of slotted casing liners in order to stabilize the weathered rock of the water-bearing zone.

Few boreholes in weathered granodiorites have been pumped at their full capacity, and hence little is known about the productivity of these aquifers. However, three production boreholes (AJ19-33, AJ19-34 and AJ19-35), located on the National Textile Ltd. property in Matsapha, have reportedly been delivering a combined yield of about 9 L/s on a relatively steady basis for over two years, with no significant drawdown in the aquifer.

Pegmatites in the weathered (mostly Middleveld) granodiorites can form productive zones. For example, three recently drilled boreholes (not included in the report database) yielded over 8 L/s at a pegmatite/weathered granodiorite contact.

5.4.2.2 Mliba Granodiorite (GM)

The Mliba Granodiorite hydrogeologic unit is present in one relatively extensive area, located around the community of Mliba in the northern Middleveld. The rock is generally massive, has few intrusions, and is not very susceptible to weathering. The Mliba area is relatively dry and borehole yield data was not sufficient to determine trends but, in general, this is not considered likely to be a productive unit.

5.4.3 MICROGRANITES AND GRANOPHYRES (MG)

Granophyre bodies and micrognanitic dykes are present in many of the intrusive and volcanic units scattered throughout the Middleveld, Lowveld and Lebombo areas, and have proven to be poorly productive. A number of granophyre plutons elongated in a north-south direction have intruded the Karroo volcanic sequence close to the contact of the basic and acidic lavas. The granophyres are much more resistant to erosion than the surrounding basalt. They are usually medium grained and holocrystalline, while the associated dykes are fine grained and often porphyritic (Photo 9). The granophyres were emplaced as steeply eastward dipping sheets into the crest of the monocline, and may represent aborted feeders (Wilson, 1982).

There are records of only four boreholes penetrating the MG unit, and as such the statistics are not significant. As these are not areally extensive units, and since they are of low permeability, they are not hydrogeologically important.

5.5 METAMORPHIC UNITS

5.5.1 GNEISSES (GW, GN AND GL)

The principal gneiss hydrogeologic units, starting with the oldest (see Table II), are: Ngwane (GW), Other Gneisses (GN) and Nhlangano (GL). There are records of 395 boreholes in Gneiss units (see Table III) of which 204 have records of blown yields ranging up to 12 L/s, and averaging 1.53 L/s. Thirteen percent (26) of the boreholes were dry, compared to an average of 15.3% for all boreholes drilled in Swaziland. A breakdown of blown yield statistics is shown on Figure 35.

Gneiss units are not usually weathered to any great extent. However, amphibolite inclusions are relatively abundant, and generally form favourable water-bearing zones. Fractured and sheared zones, although relatively rare, are also good targets for boreholes in this unit. Visser (1956) reached a similar conclusion, based on experience in the Barberton area of the RSA. Average borehole depths for these units are summarized in Figure 36.

It is also noteworthy that Robins (1978) concluded that 39% of boreholes drilled in gneissic terrain yielded less than 0.05 L/s, and a similar percentage (40%) was estimated using data from this Project.

5.5.1.1 Ngwane Gneiss (GW)

The Ngwane Gneiss hydrogeologic unit is distributed mostly in a 40 km wide diagonal band extending across the Middleveld and Highveld, from a position of about orthophoto 36 in the northeast, to AY01 in the southwest of Swaziland. This unit is referred to as the Swaziland System "infra-structure" by Hunter (1957). Exposures are confined largely to rapids on the major rivers. Amphibolites, and more rarely serpentinites, are common within the Ngwane Gneiss as localized zones, narrow bands, or small ovoid bodies. Pegmatites are also abundant, occurring as dykes, veins or pods (Photo 10). Dyke pegmatites have sharp contacts and appear to be related to joint and fracture directions (Hunter, 1957).

There are records of 308 boreholes in the GW unit (see Table IV), of which 161 have records of blown yields, ranging up to 12 L/s and averaging 1.58 L/s. Analyses determined that seven percent (12) of the boreholes had yields less than 0.01 L/s, compared with 13% for all gneiss units. The maximum reported yield is from borehole AA34-31. However, as this is not a Project borehole, it was not possible to confirm the lithology and yield. The highest yielding Project borehole (AI29-01, 6.6 L/s) penetrated mostly weathered coarse grained gneiss and had a first water strike (5 L/s) in a small fracture, located at a depth of 55m below ground. The remaining yield was picked up at a dolerite contact, near the bottom of this 76.2m deep borehole.

5.5.1.2 Other Gneisses (GN)

This group of metamorphic hydrogeologic units includes gneisses belonging to the Post Swaziland Gneiss Complex, and includes Mhlatuzane, Tsawela and Mahamba Gneiss units. As with Ngwane Gneiss, these units have abundant amphibolite inclusions and are cut by many dykes and veins of granite, pegmatite, quartz and diorite.

Tsawela Gneiss is a distinctive hornblende/biotite tonalitic gneiss, which appears to have intruded the Ngwane Gneiss in some areas. Mhlatuzane Gneiss is a hornblende tonalitic gneiss of plutonic form, which is commonly foliated. Mahamba Gneiss is present mainly on Map Sheets 24 and 28 in southwest Swaziland, and is a high grade semi-pelitic garnetiferous gneiss included in the Bimodal Suite (Wilson 1982).

There are records of 43 boreholes in the GN unit (see Table IV) of which 22 have records of blown yields, ranging up to 4 L/s and averaging 1.43 L/s. Twenty-six percent (6) of the boreholes had yields less than 0.01 L/s. The highest yielding borehole was AE15-02, located in the Ezulwini valley. This borehole first encountered a 1 L/s yield in a confined fracture zone at 22.3m, and the yield increased to 4 L/s when the borehole reached a total depth of 43m.

5.5.1.3 Nhlangano Gneiss (GL)

Nhlangano Gneiss is typically a pale coloured hydrogeologic unit, which weathers to a pinkish-red colour and is present in the form of folded mantled domes. This unit is located primarily in the Nhlangano area of south central Swaziland. Amphibolite bodies and dolerite dykes are relatively scarce in this unit. In general, yields from this unit have been poor, with the better producing zones close to intrusives, xenoliths and dolerite or diorite contacts. The dolerite intrusions in this unit are finer grained and of different mineral composition than the dolerites dykes in the Karroo sediments (Photos 11 and 12).

There are records of 44 boreholes in the GL unit (see Table IV), of which 21 have records of blown yields. These yields ranged up to 5 L/s and averaged 1.28 L/s (see Figure 35). Thirty-eight percent (8) of the boreholes had yields less than 0.01 L/s. It is significant to note that boreholes penetrating massive gneiss, which were not associated with a fault, fracture or other notable discontinuity, had an even higher percentage (47%) of dry holes.

The highest yielding borehole (BN16-01) penetrated mostly baked gneiss, and the entire yield came from a small fracture located at a depth of 49m. The total depth of this borehole was 61m.

Contacts With Amphibolites (GL/AM)

The hydrogeological importance of amphibolites within other granitoid rocks was briefly discussed in Section 5.4.2.1. Amphibolites are crystalloblastic rocks consisting mainly of the mineral amphibolite, which is a complex iron, calcium and sodium aluminum silicate. Basically, it is a highly bedded gneiss. These units typically are less prone to weathering than the surrounding country rock.

This sub-unit includes the Dwalile Metamorphic Suite, and the Shiselweni Amphibolites. The rocks of the Mkhondo Valley Metamorphic Suite have been included in the report with those of the Mozaan Group. The rock types within these two units are of very limited extent, and are essentially untested by drilling.

There are, however, hydrogeologic records of nine boreholes which have predominantly penetrated the Amphibolite Unit. Three have records of blown yields, ranging up to 5 L/s and averaging 3 L/s. None of these boreholes had yields less than 0.01 L/s.

The highest yielding borehole (BA28-01, 5 L/s) penetrated grey coarse grained amphibolite, consisting of hornblende and feldspar and occasional round grains of quartz surrounded by hornblende. The first water strike (1 L/s) was at a depth of 37m below ground. The remaining yield was picked up in isolated zones in the bottom of this 83.3m deep borehole.

It is suspected that many more boreholes have penetrated amphibolites but were not recorded in the database, due to the penetration thickness being relatively thin, or because relevant information was not included in the borehole log.

5.5.2 DYKES, SHEETS, SILLS AND OTHER INTRUSIVES (DO)

Massive dykes, sills and intrusive sheets, composed of dolerite and diabase, are relatively common throughout Swaziland. These hydrogeologic units have been identified as moderately productive. Dolerite sills are often areally extensive and are commonly exposed in river banks and eroded gullies (Photo 15;). The contact zone between the intrusive and the country rock is often more productive than the rocks located further from the contact. Differential cooling of the intrusive results in formation of small fractures in the chilled zone of the intrusive, which may be enhanced by continued movement of the internal fluids. The adjacent country rock also becomes "baked", hardened and possibly fractured during the intrusion. Subsequent weathering, which usually commences near the surface, enlarges these fractures and, provided that minerals were not redeposited, creates a good aquifer.

In the southwestern part of Swaziland, dolerite intrusives occur mostly in the form of sills rather than dykes. Numerous dolerite sills intrude the Nhlangano Gneiss, Mozaan quartzites, the Hlatikulu and Kwetta granites and rocks of the Dwyka Group. Borehole BH24-01, with a yield of 2 L/s, was drilled through Dwyka tillite and dolerite sill contact. Borehole BK25-51 was drilled through Kwetta granite into a dolerite sill with a reported blown yield of 2 L/s.

There are records of 46 boreholes penetrating either dolerite or diabase rock and encountering water. A majority of the boreholes encountered either dolerite sills or dykes; of these, 35 had records of blown yields ranging up to 5 L/s and averaging 0.95 L/s (see Figure 35). Thirty-nine percent (11) of the boreholes yielded less than 0.01 L/s (as compared to 15.3% for all units in Swaziland). These statistics suggest that borehole yields from the DO unit are highly variable. In some areas, the dolerite dykes and sills act as dams or create perched water tables, respectively. Evidence for these effects is provided in the form of wet spots and/or seeps or springs located adjacent to intrusive features.

5.6 VOLCANIC UNITS

The Volcanic group of hydrogeologic units include Usushwana Complex (UC), Greenstone Belt (GB), Insuzi Group (IZ) Sabie River Basalts (BA, BA/WE and BD) and Lebombo Rhyolites (LR). There are records of 361 boreholes in volcanic rocks (see Table III), of which 224 have records of yields. Yields range up to 8 L/s.

5.6.1 USUSHWANA COMPLEX (UC)

The Usushwana Complex hydrogeologic unit is made up mainly of hard, resistant rock types forming high ground, and is not considered to be favourable for groundwater exploration. This unit is found primarily in 1 to 3 km wide bands located in the southwest corner of the country.

Yield data is available for only two boreholes within this unit (see Table IV). These boreholes yielded flows of 1.0 and 4.0 L/s from weathered gabbro.

5.6.2 INSUZI GROUP (IZ)

The Insuzi Group is a member of the Pongola Supergroup and includes andesitic lavas and felsites, with schist and quartzite interbeds. There are records of 28 boreholes which have penetrated the Insuzi Unit (see Table IV). Fifteen have records of blown yields, ranging up to 6.6 L/s and averaging 1.1 L/s. Thirty-three percent (5) of these boreholes were dry.

Boreholes in andesitic lavas and felsites are variable in their productive capacity, although the typical yield is less than 1 L/s and several dry holes have been drilled. Several holes have also been completed in schists, with similar results. Other than for Project boreholes, it is not generally known whether a borehole obtains its production from fractured fresh rock or from the weathered zone. The highest known yield (borehole AX14-01) was 6.6 L/s, and issues from the weathered zone in andesitic lava.

The Insuzi rocks south of Maloma on Sheet 30, which are in the dry Lowveld-Middleveld transition area, are particularly unproductive. Five project holes drilled to test the andesitic rocks in this area were all dry. It was concluded that these rocks were thermally metamorphosed by intrusion of the Kwetta/Mtombe, Hlatikulu, and Mswati granites in this area, and any pre-existing fracture permeability was destroyed.

5.6.3 SABIE RIVER BASALTS (BA, BA/WE AND BD)

The Sabie River Basalt unit is primarily located in the relatively dry Lowveld region. Sabie River basalts are tholeiitic (olivine-poor). Basalts in areas where deep weathering and dykes are relatively rare have been designated as the BA hydrogeologic unit. In many of the low lying areas of the southern Lowveld, the depth of weathering is in the 20 to 40m range. These zones have been designated as hydrogeologic unit BA/WE.

Hunter (1961) and Urie and Hunter (1963) recognized four major basalt types in Swaziland: Lubuli (most common); Mgwanwini (typically interbedded porphyritic); Nsoko; and a more localized Sinyamantulu type occurring near the base of the succession. The distinction between the types is based on texture and lithology.

Swarms of dolerite dykes and extensive strike faults cut through part of the basaltic succession on Map Sheets 26 and 31 in the areas to the west of Big Bend and Lavumisa (these areas have been designated as the Dyke Swarm hydrogeologic unit BD). However, bedrock exposures are too poor to allow for reliable basalt unit dip measurements to be made, and to determine the amount and extent of strike faulting (Urie and Hunter, 1963).

There are records of 209 boreholes in Sabie River Basalt units (see Table III). Of these, 162 have records of blown yields, ranging up to 6.7 L/s and averaging 1.0 L/s. Fourteen percent (24) of these boreholes yielded less than 0.01 L/s (as compared to 15.3% for all units in Swaziland).

5.6.3.1 Massive Basalt (BA)

The BA hydrogeologic unit is composed of fine grained, massive, thick bedded basalt flows, in various shades of dark grey and dark green (Photo 16). By definition, this unit designation is restricted to fresh basalt rock, where weathering is not extensive and dolerite dykes are rare. Local fracturing provides the water-bearing zones.

There are records of 80 boreholes in the BA hydrogeologic unit. Of these boreholes, 51 have records of blown yields (see Figure 37), ranging up to 7.0 L/s and averaging 0.76 L/s. Of these boreholes, eighteen percent (10) were dry. The highest yielding borehole (BL46-01) is located on the footwall side of a rhyolite intrusion into relatively massive basalt. This 104m deep borehole penetrated 23m of essentially dry weathered basalt, and the remainder was in fine grained basalt with some quartz filled amygdales. Water was first struck (0.5 L/s) at a depth of 51.5m. This hole was uncharacteristically **deep** for boreholes sited in the BA hydrogeologic unit (see Figure 38).

Siting of boreholes in this type of unit is very critical and, if hydrogeological targets are carefully selected and surveyed in the field (possibly using geophysical techniques), the success ratio can be greatly improved.

5.6.3.2 Weathered Basalt (BA/WE)

Weathering generally is deepest in low lying areas along intermittent streams, and is often present in many discrete zones within the same borehole, as a result of the weathering of successive basalt flows. There are records of 25 boreholes in the Weathered Basalt hydrogeologic unit. Records of blown yields range up to 6.7 L/s and average 2.44 L/s (Table III). Only one of the boreholes was dry. There are five boreholes with yields of about 7 L/s (BA45-01, -02 and -03, BL46-02 and BC46-62). The log of BA45-01 is included in Appendix E.

5.6.3.3 Dyke Swarm Basalt (BD)

The Dyke Swarm Basalt hydrogeologic unit extends the full length of the basalt flows, and almost the full length of the country. Swarms of closely spaced north-south trending relatively fresh dolerite dykes have intruded the basalt flows. The dolerite dykes are less susceptible to weathering than the basalts, and both these and the hardened, baked basalts near the dyke contacts form prominent closely spaced ridges. Small scale fracturing along the altered dolerite/basalt contact zones forms low-yielding aquifers, with highest yields being obtained in low-lying areas. Outcrops are confined mainly to stream valleys. Urie and Hunter (1963) indicate a common dyke width of between 20 and 30m, and a westerly dip of 70° to 85°.

There are records of 104 boreholes in the BD unit (see Figure 37). Of these, 86 have records of blown yields ranging up to 6.8 L/s and averaging 0.72 L/s. Fourteen of these boreholes (16%) yielded less than 0.01 L/s. The highest yielding borehole was BR41-51 (6.6 L/s) located near Emsuzaneni, south of the Lavumisa High School in the southern Lowveld. However, as this is not a Project borehole, it was not possible to confirm the lithology and yield. The highest yielding Project borehole (W44-01, 3.3 L/s) penetrated mostly fine grained basalt with some amygdales and had a first water strike (0.7 L/s) in a confined water-bearing zone, located at a depth of 18m below ground. The remaining yield was picked up at a dolerite contact, near the bottom of this 64m deep borehole.

The dykes appear to be relatively impervious, and have the effect of compartmentalizing the aquifers and limiting their areal extent and recharge capability. When a new borehole is installed in these types of aquifers, they become partially dewatered, causing the borehole yields to gradually decline to a relatively low safe yield. The safe yield might be as little as 10% of the blown yield. Hence, rationalized water balance calculations are very important for determining the long term (i.e. safe) yields from these units (see additional information in Section 6.4).

Frommurze (1937) summarized the results of boreholes in dyke swarm basalts in northern Natal, RSA. As in Swaziland, the dykes are difficult to distinguish from the basalts, and in many places they occur very close together, often not more than 15m apart. He reported a 33% failure rate (defined as yielding less than 0.05 L/s) out of 150 boreholes drilled, with an average depth of 57m and an average yield of 0.8 L/s. Fourteen holes (9%) were drilled deeper than 90m, with a 38% failure rate. These statistics are very similar to those in Swaziland, when all boreholes are considered.

5.6.4 LEBOMBO RHYOLITES (LR)

The Lebombo Rhyolite hydrogeologic unit is a thick succession of mostly acidic volcanic rocks disconformably overlying the Sabie River Basalts, with some interfingering of rhyolites into the upper part of the basalts. The rock composition of the LR unit varies from rhyolite to dacite, both rock types containing phenocrysts of plagioclase, quartz, clinopyroxene and magnetite in a fine-grained devitrified matrix.

The cross-sections on the Geological Map of Swaziland (Wilson, 1982) indicate an average dip of less than 5° (Photo 17). However, determination of dips in the rhyolites is difficult and, where possible, the results are quite variable. Hunter (1961) has noted "highly involved and over-folded pseudo-flow structures" in the rhyolites and states that dips are reliable only if taken at recognized contacts between flow units. Agglomerate beds are generally 15 to 30m thick. These consist of angular fragments, generally of pebble size but ranging up to a few feet across, set in a yellowish brown to reddish brown, fine grained ground mass containing fragmented quartz and stained by iron oxide. There is usually a coarsening upwards in grain size, while the rock becomes less compact and more vesicular and pumiceous.

Only a few faults of any extent have been mapped, although there are many small faults at the western edge of the rhyolites. Granophyre and dolerite intrusions in the form of narrow dykes are rare, but occasionally present. Cleverly (1977) concluded that all the dykes cutting the rhyolites seem to have a vertical dip.

Typically, the Lebombo rhyolite is covered by a thin soil often not exceeding 10m in thickness, underlain by a weathered zone generally less than 10m thick. The fresh rhyolite is hard and generally non-water bearing. All water strikes in the non-faulted or fractured rhyolites in the Lebombo hills were found to occur within the zones of weathering with typically low yields of the order of 0.3 L/s.

Several springs were mapped in the Lebombo hills, where it was observed that the frequency of occurrence increased with distance down dip towards the east, where stream incision into the topography also increased. Most of these springs may be described as depression springs, as they typically issue from points where there is a break in the topographic slope. Ferricrete deposits of one to two metres in thickness commonly occur where springs discharge on to a gentle slope, allowing time for the ferrous iron in the groundwater to oxidize within a short distance along its surface flow path, where ferric oxide is precipitated.

Excluding the boreholes located in obvious fault zones (LR/FZ), there are records of 99 boreholes which are located in the LR hydrogeologic unit, of which 33 have records of blown yields (see Figure 37), ranging up to 4.5 L/s and averaging 0.66 L/s. Twenty-one percent (7) of the boreholes were dry.

The highest yielding borehole (AV49-81) was reported to have yielded 4.5 L/s. Since this is not a Project borehole, it was not possible to confirm the lithology and yield. However, it is significant to note that this borehole is located on a ridge in a relatively arid area and, as it will not likely be hydraulically connected to a large underground reservoir (aquifer), this yield is probably not sustainable.

With a few exceptions, Project boreholes in the LR unit have been very disappointing in terms of water yield. Seven of the 16 holes drilled were dry, and only four had blown yields exceeding 1 L/s.

The highest yielding Project borehole (AG45-01, 2.0 L/s) penetrated mostly weathered porphyritic rhyolite with feldspar phenocrysts and quartz. The first water strike (0.18 L/s) was at a depth of 55m below ground. The remaining yield was picked up in isolated zones near the bottom of this 94.5m deep borehole. The maximum recorded borehole depth drilled in the LR unit is 122.5m (see Figure 38).

Predictably, the poorest rate of success was in boreholes drilled in the massive central portion of the rhyolite flow units. Four of the seven holes drilled in these areas were dry, while the remaining three had yields not exceeding 0.3 L/s.

5.6.4.1 Regional Fault and Fracture Units in Lebombo Rhyolites (LR/FZ)

As would be expected, the rate of success of boreholes sited along lineaments which are presumably joint controlled was variable. Six boreholes (all Project boreholes) are known to have encountered significantly fractured rhyolite bedrock, and hence have been assigned either LR/FZ or FZ/LR designations (Photo 18). Yields from these boreholes ranged from 0.17 to 6.7 L/s, and averaged 2.42 L/s.

Boreholes AG45-01, AF46-01, AE47-01, AD48-01 and AD48-02 were drilled in an attempt to intersect the tops of flow units and/or a previously unmapped fault. Two boreholes located along a fault (AD48-01 and AF46-01) had high yields (4.0 and 6.7 L/s, respectively); however, the degree of inter-connection along this fault is still not well established. Boreholes AD48-01 and AD48-02 were drilled with the aim of encountering a dipping breccia zone, and yielded 4 L/s and 0.2 L/s, respectively. Borehole AF46-01 was located in a low-lying area 8 km along strike of the same lineament, and had a yield of 6.7 L/s.

Three holes were also drilled on mapped faults and all were successful, giving yields ranging from 0.6 L/s to 2.5 L/s.

It should be noted that all except three of the holes drilled to test lineation trends were drilled on relatively high land, usually near the heads of valleys which follow the jointing, because these are the main settled areas and have reasonable access. Jointing, however, is likely to be least well developed at these locations. Drilling lower in the valleys is expected to give better results.

5.7 GREENSTONE BELT UNIT (GB)

The Greenstone Belt hydrogeologic unit is located in the northwest corner of Swaziland, and is composed primarily of very old alternating sediments and volcanics. The hydrogeological potential of this area has not been explored very extensively due to the rugged terrain and high rainfall. Springs are common in the Greenstone Belt; however, due to their relative inaccessibility, only a small proportion have been mapped to date.

The Greenstone Belt is thought by many workers to be the oldest, best preserved, and least metamorphosed vulcano-sedimentary succession known (Kent, 1980). The basal sequence of the Greenstone Belt is known as the Onverwacht Group (Table II). This, in turn, is overlain by Fig Tree Group flysch sediments and then by Moodies Group Molasse sediments.

Regional metamorphism to greenschist facies and tight folding along steeply plunging northeast-southwest striking fold axes, together with high-angle thrust faulting toward the interior of the Greenstone Belt, followed sedimentation and was superseded by northwest-trending cross-folding. The entire belt has been telescoped by thrust faulting, resulting in much repetition of lithologic sequences. These faults are characteristically open and form potential conduits for infiltrating groundwater.

Yield data in Swaziland is available for 14 boreholes in the GB unit and ranged from dry (less than 0.01 L/s) up to 8 L/s, averaging 2.58 L/s (see Table IV). Only two of the 15 boreholes were dry. The highest yielding borehole (X08-01) is located about 2.5 km east of the Ngwenya border post. This borehole penetrated clay and weathered schist to a depth of 21m. First water was not struck until a small quartz vein was encountered at 45m, and the principal water yielding zone was at a schist/phyllite contact.

While relatively few boreholes have been drilled in this unit to date, intense folding, faulting, fracturing and the presence of dykes, all suggest that it is potentially relatively productive. Secondary permeability along fracture zones of different types can extend to considerable depths (van Eeden, 1956). This has been confirmed by observed water inflows of up to 8 L/s from individual fractures intersecting mine workings, at depths of 465 and 550m below ground surface in Asbestos (Pty.) Ltd.'s Bulembu Mine.

As a result of the relatively sparse amount of data in this area, all the rock types have been grouped together to comprise one hydrogeologic unit. However, the following sections provide general information on the characteristics of the principal sub-units of the Greenstone Belt hydrogeologic unit.

5.7.1 ONVERWACHT GROUP

These rocks are made up of basic and ultrabasic lavas, regionally metamorphosed to talcose and talc-carbonate schists and amphibolites, which are extensively silicified. Metasediments, including greywacke, chert, marl, ironstone, and shale, are relatively minor within this sequence.

The predominantly basic rocks are typically highly weathered and borehole yields are high (Z08-01 yielded 6.7 L/s). Where areally extensive, these rocks have the potential for sustaining moderately high yields all year round. Acidic lavas have not been explored. However, as they are less prone to weathering, yields are not likely to be as favourable as those in the basic rocks.

5.7.2 FIG TREE GROUP

The Onverwacht Group is conformably overlain by the flysch sediments of the Fig Tree Group, consisting of coarse greywackes, shale, phyllite, quartzite, and conglomerate. Boreholes drilled in talc schist rocks have generally been dry, especially those located close to granite intrusions.

5.7.3 MOODIES GROUP

The molasse type sediments of the Moodies Group rocks consist primarily of quartzites and conglomerates. Weathered quartzites form excellent aquifers in this sub-unit, and there are also numerous permanent springs present (Visser, 1956).

5.8 SEDIMENTARY UNITS

All sedimentary units in Swaziland have been subjected to some degree of low temperature metamorphism. The sedimentary units of the

Greenstone Belt (Fig Tree and Moodies Groups) have already been described in Sections 5.7.2 and 5.7.3, and will not be discussed in this section. The remaining principal sedimentary hydrogeologic units belong to the Mozaan and Karroo Groups. The Karroo sediments are typically only locally altered by dolerite intrusives.

There are records of 184 boreholes which are located in sedimentary units, of which 131 have records of blown yields, ranging up to 8.4 L/s (see Table III). Nineteen percent (25) of the boreholes had yields less than 0.01 L/s, compared to 15.3% for all boreholes in Swaziland.

The highest yielding borehole penetrating a sedimentary unit (AF41-31, 8.4 L/s) is located in an area east of Mpaka. This borehole was in Nkondolo Sediments (unit KN); however, as this is not a Project borehole, it was not possible to confirm the lithology and yield. The highest yielding Project borehole (BC27-01), located in Mozaan slates and shales, had a blown yield of 6.7 L/s and is 67.1m deep.

5.8.1 MOZAAN GROUP (MZ)

The sediments of the Mozaan Group hydrogeologic unit lie disconformably over the Insuzi Group, and cover a somewhat larger area than the Insuzi. The MZ unit consists of quartzites interbedded with shales which are often altered to slate, phyllite, or schist (Photo 19). Hunter (1963) has divided the succession into a series of 14 quartzite and 14 shale horizons, capped by a 150m thick, fine-grained, amygdaloidal basalt.

The quartzites are light coloured, variable in grain size, well jointed, and form prominent outcrops. Bands and interbeds of conglomerate occur in the lower quartzite horizons.

Hunter (1963) suggests that the maximum total thickness of the unit is about 4,260m; the lower 1,110m, which is exposed in the Mahlangatsha-Gege area in Map Sheets 23 and 28, is predominantly arenaceous. The remaining upper portion, in the Kubuta area in Sheets 24, 25, and 29, is predominantly argillaceous.

Where well fractured, both the quartzites and schist/shales can provide highly productive borehole yields, especially where the unit is also slightly weathered. However, as shales are generally less prone to fracturing than quartzites, boreholes penetrating quartzites have been more productive than shales.

Boreholes located in synclinal zones have been particularly successful, possibly due to additional fracturing related to folding. Fresh shale beds, being harder and more fissile than the weathered zones, are often more permeable than the weathered zones. It is postulated that the weathered shales form aquicludes in some areas. Weathering in fractured zones has been encountered at depths in excess of 70m in some areas. Hence, if sufficient water is not obtained at a shallower depth, consideration should be given to continue drilling until all weathered zones appear to have been penetrated.

There are records of 25 boreholes in the MZ unit (see Tables III and IV). Of these boreholes, 16 have records of blown yields ranging up to 6.7 L/s and averaging 2.29 L/s (see Figure 39). Only thirteen percent (2) of these boreholes yielded less than 0.01 L/s.

The highest yielding borehole (BC27-01) penetrated mostly shale and slate, with occasional weathered quartz bands. The first water strike (5 L/s) was in an unconfined zone located near the base of weathered slate, at a depth of 30.5m below ground. The remaining yield, up to a cumulative total of 6.7 L/s, was picked up in isolated zones in the bottom of this 67.1m deep borehole.

5.8.2 KARROO SYSTEM (KD, KE AND KN)

The Karroo sediment hydrogeologic units include, from the base upwards, Dwyka Group (KD), Ecca Group (KE), and Nkondolo Group (KN).

There are records of 159 boreholes in the three Karroo hydrogeologic units (see Table III). Of these boreholes, 115 have records of blown yields, ranging up to 8.4 L/s and averaging 2.5 L/s. Twenty percent (23) if the boreholes were dry. The highest yielding borehole (AF41-31) was reported to have yielded 8.4 L/s; however, as this is not a Project borehole, it was not possible to confirm the lithology and yield.

There are numerous dolerite dykes intruding the Karroo sediments. Often, the indurated baked zones along the dyke contacts are slightly fractured and, if not plugged with secondary mineralization, are permeable and water-bearing. In the eastern Karroo sediments (Lowveld area), the permeable zones are only a few centimetres thick; however, borehole yields of between 0.6 and 4 L/s are common. This compares to normal yields of less than 0.06 L/s from relatively massive rock in a similar area. These comparisons, however, must be tempered with the knowledge that the degree of effort expended in trying to position the boreholes correctly relative to the dyke dip and location of the water table, is not always taken into account during borehole siting.

When siting boreholes, it was found that siting on fault zones gave poorer than average results and a 50% failure rate, while contact zones of the Karroo sediments with dolerite dykes, sills or other rocks gave better than average results. Boreholes drilled on high ground also tend to be more successful. This is likely due to a more active leaching (and hence weathering) of rocks by the infiltrating groundwater in the high areas, with consequent opening up of joint and fracture planes.

Fractures in the contact zones tend to close at increasing depths below the reach of weathering processes and hence, once a borehole in these units penetrates to depths of more than about 20m below the water table (i.e. typically no more than 60m below ground), the frequency of water strikes decreases substantially. Similar experiences were reported by Enslin (1961, 1964), Van Wyk (1963) and Vegter and Ellis (1968), who conducted studies in adjacent areas of the Republic of South Africa.

5.8.2.1 Karroo Dwyka Sediments (KD)

The Karroo Dwyka Sediments hydrogeologic unit is composed of tillites and glaciolacustrine shales that were deposited by ancient glaciers. Near surface occurrences are not generally extensive, and hence the unit is not very important hydrogeologically. Isolated patches are found along the Sicunusa and Ngwavuma valleys in southern Swaziland.

Dwyka sediments in the Lowveld areas are not widespread, and are usually relatively thin where found. When unweathered, the tillite is composed of hard angular pebbles and cobbles, set in a silty to sandy matrix (Photo 20).

There are records of only four boreholes located in the KD unit (see Table IV). Blown yields ranged up to 2 L/s, with only one borehole having a yield less than 0.01 L/s.

The highest yielding borehole (BH24-01) penetrated 15m of tillite and then a dolerite dyke to a total depth of 36.6m. The first water strike was in tillite at a depth of 18.3m below ground; however, it is believed that the principal water yielding zone was along the tillite/dyke contact rather than in the tillite itself.

Another borehole (AZ06-01) encountered silty tillite below a shale unit at a depth of 36.6m, and eventually penetrated into the underlying granite at a depth of 51.8m (see log in Appendix E). In this situation, none of the three units penetrated yielded any water. Studies in southwestern Transvaal, RSA (De Villiers, 1961) concluded that Dwyka tillite is generally a poor aquifer, with water found only in occasional joints or fractures. The Dwyka shale in that area also has low permeability, but intense jointing of the shale in narrow zones (often not more than 0.3m wide), along contacts with dolerite dykes and sills, commonly forms aquifers.

5.8.2.2 Karroo Ecca Sediments (KE)

The Karroo Ecca Sediments hydrogeologic unit is composed of sedimentary deposits ranging from claystones to sandstones. The lowermost (oldest) beds are claystone and shales, which Wilson (1982) suggests are likely of prodeltaic origin. This is overlain by the thick prograding fluvio-deltaic sequences of the Middle and Upper Ecca members, which include sandstones, coals and claystones sometimes exceeding 700m in thickness. The sandstones of these sequences are commonly feldspathic and micaceous, with well developed cross-stratification (Photo 21).

There are records of 107 boreholes in the KE unit, of which 76 have records of blown yields, and these range up to 4.8 L/s (see Figure 39 and Table IV). Twenty-six percent (20) of the boreholes had yields less than 0.01 L/s.

The highest yielding borehole (BJ11-51) was reported to have yielded 4.8 L/s. This is not a Project borehole, and hence it was not possible to positively confirm the lithology and yield. However, the borehole is located in the Middleveld area and probably penetrated the Lower Ecca siltstone unit, which is known to be relatively productive.

The highest yielding Project borehole (BE09-01, 4.0 L/s) obtained water from a small fracture located at a depth of 18m below ground. The remaining yield was picked up in isolated zones in the bottom of this 127.3m deep borehole. This borehole was significantly deeper than the average depth of 67.8m for boreholes in this unit (see Figure 40 and Table IV).

Yields from boreholes in the Lower Ecca and Dwyka Groups, located mostly in the lower Middleveld areas of south central Swaziland, have significantly higher yields than the same lithologic units located in arid Lowveld areas. This is partly due to the higher rainfall in the Middleveld areas, but mainly attributed to facies changes which result in frequent occurrences of permeable pebbly claystone.

Based on work in the Northern Transvaal, Van Eeden (1961) reached a similar conclusion. He also suggested that, where intruded by dykes, indurated rock zones typically extend for widths of a quarter to a half that of the dykes. A high percentage of successful boreholes have been drilled into these hardened zones, which will sustain open fractures more readily than the unaltered, softer sediments.

Much work on the hydrogeology of the Karroo sediments has been carried out in South Africa. In northern Natal and Zululand, Van Wyk (1963) found that the thinly bedded Lower Ecca shale was generally a good aquifer, except when covered by the more massive Middle and Upper Ecca shales. He reports no failures in 73 boreholes drilled in the Lower Ecca sediments in the Vryheid and Babanengo districts. He attributes this to a high joint frequency in the thinly bedded sediments which, coupled with the bedding planes, permits circulation of rain water and groundwater. Opening of these discontinuities due to weatherings provides a substantial increase in secondary permeability of these rocks. In contrast, only 20 to 30% of the boreholes in Middle and Upper Ecca shales yielded more than 0.11 L/s.

Dolerite dykes and sills are very common in the Karroo Ecca Sediments (Photos 13 and 14). Experience in Swaziland and in adjacent areas of the RSA (Vegter and Ellis, 1968) suggests that boreholes in the Lowveld areas which were located in or near moderately thick (5 to 8m) dolerite dykes or sills had much better yields than those located entirely in the adjacent Ecca sedimentary bedrock unit. This is generally due to penetration of better developed jointing and fracturing in the outer edges of dolerite dykes. For example, three boreholes (AP39-01, AP39-02 and AP37-01) penetrated a number of small slightly weathered small fractures in fine grained massive dolerite, and yielded 2 L/s, 5 L/s and 4 L/s, respectively. This can be compared with the results from 14 boreholes penetrating only Karroo sediments (within a radius of 10 km of two of the boreholes noted above) which yielded an average of less than 0.6 L/s. In one specific area, three boreholes (AN40-01, -02, -03) yielded less than 0.1 L/s.

De Villiers reports variable yields from sandstones of the Ecca Group in the southwestern Transvaal. In that area, he reports that, generally, the greater the thickness of the sandstone, the higher the yield and the higher the percentage of successful holes.

5.8.2.3 Karroo Nkondolo Sediments (KN)

The Karroo Nkondolo Sediments hydrogeologic unit includes the Molteno Beds, Red Beds, and Cave Sandstone, from oldest to youngest. The Molteno Beds consist of fine to coarse grained sandstones with thin conglomerate layers in their upper portions. The Red Beds are typically fine grained, massive mudstones and siltstones with a grey sandstone parting in the middle. At the top of the KN unit is the Cave Sandstone which is a uniform, fine grained sandstone.

There are records for 48 boreholes located in the KN unit (Table IV), of which 35 have records of blown yields, ranging up to 8.4 L/s (see Figure 39). Eight percent (3) of the boreholes were dry.

The highest yielding borehole (AF41-31) apparently produced 8.4 L/s. However, as this is not a Project borehole, it was not possible to confirm the lithology and yield. The highest yielding Project borehole (AF41-03, 2.0 L/s) penetrated mostly sandstones and shales, and had a first water strike (0.3 L/s) in a sandstone bed located at a depth of about 29m below ground. The remaining yield was picked up in isolated zones towards the bottom of this 83.3m deep borehole.

Sixty percent of the holes drilled in the KN unit did not encounter any dolerite, a primary target. Although only two of the holes drilled were dry, yields were quite low, averaging only 0.54 L/s. This is an indication that, although jointing and fracturing in these sediments may be relatively closely spaced and widespread, high yielding fractures are not common.

5.8.3 RECENT DEPOSITS (AL)

Thin deposits of loose or partially consolidated sediments of recent origin are found in most areas of Swaziland. These mostly include alluvium (AL) and colluvium. Extensive studies of depositional environments of shallow soils and their erosion potential have been carried out. Background reports on these studies include Price Williams and Watson (1982); Price Williams, Watson and Goudie (1982) and Watson, Price Williams and Goudie (1984).

In the Middleveld and in Highveld areas, the major rivers have often cut down into solid bedrock. As would be expected, alluvium is more commonly found in the larger river valleys of the lower Middleveld, where the valleys broaden out and sediments are deposited as a result of decreased river flow velocities.

Less extensive and older alluvial terrace deposits occur in many isolated places, often perched on hill slopes of the Highveld and Middleveld, and occasionally as high as 20m above the level of nearby valley bottoms (Photo 22).

Broad flat alluvial deposits are rare and are found only in the lower Middleveld and upper Lowveld areas. These are typically composed of alternating beds of fine to coarse sand and gravel and rarely exceed thicknesses of 35m where these deposits extend below river level.

Colluvial and possibly eluvial processes in the Highveld and Middleveld are responsible for accumulating permeable sediments, which often form small but useful aquifers at the base of steep hillsides, many of which feed numerous springs. The alluvial material in these terraces is often cemented to form ferricrete (Watson, 1987).

Saturated alluvial deposits which will yield water to a borehole in significant quantities are very limited in extent in Swaziland, and have a patchy distribution along the major rivers. Boreholes completed in alluvium during the project have only been drilled along the Komati River (in Map Sheets 3 and 7).

There are records of only 10 boreholes in the AL hydrogeologic unit (see Table IV). Of these, seven boreholes have records of blown yields, ranging between 0.36 and 5 L/s, and averaging 1.9 L/s. Not included in these data, however, are numerous shallow dug wells constructed in the banks and beds of the larger rivers during the dry season.

The record of boreholes drilled in the AL unit is relatively sparse, when considering the potential for success. This is likely due to the fact that wells constructed in alluvium require special drilling and completion techniques. This typically involves the use of casing hammers to drive casing, and installation of wire wound well screens in order to avoid collapse of the borehole walls and sediment invasion into the borehole. As these techniques are not in common use by private drilling contractors in Swaziland, wells in alluvium have often been avoided or abandoned.

Once developed, however, borehole yields may be sustainable for long periods if there is a hydraulic connection with the nearby river or water-bearing fracture zones in the surrounding bedrock.

In some areas on the steeper hill slopes, the weathering products are typically eroded away, leaving either bare rock or dongas. However, the process responsible for formation of dongas is not restricted the topographic slope. There are a number of factors, including rainfall (250 to 2,000mm); soil type; chemistry of soil and water; and groundwater flow discharge patterns.

5.9 STRUCTURAL UNITS

5.9.1 MYLONITE (MY)

The Mylonite hydrogeologic unit is a fine grained laminated rock formed from extreme microbrecciation and milling of rocks during shearing along fault planes. In Swaziland, there are two major north-south trending mylonite shear zones affecting Archean granites and gneisses and Mozaan Group sediments. The zones are present in central Swaziland, mainly on Map Sheets 13, 19, 24 and 29. These zones grade into narrow, often bifurcating, shears or faults at their extremities. Way (1961) indicates that the dip of the eastern zone, on Sheets 13 and 19, is steeply eastwards at 65 to 75°. The western zone, on Sheets 19 and 24 and trending into sheets 13 and 29, also has an eastward dip, but at shallower angles of 35 to 55°. The age of shearing is post-Mswati granite and pre-Karroo sediments (Hunter, 1961). Hunter cites much evidence of fault action. The rocks are dense, fine-grained, and often streaky, strained and variegated. Mylonites are generally very hard and resistant to weathering.

There are records of 40 boreholes in the MY hydrogeologic unit. Of these boreholes, 20 have records of blown yields which range up to 8 L/s, and average a relatively low 0.88 L/s (see Figure 39 and Table IV). Five percent (25) of these boreholes were dry.

Mylonite shear zones were extensively tested for groundwater potential on Sheet 19 in the areas of Gilgal and west of Ponjwane, where 13 boreholes were drilled into this unit. Borehole yields in the MY units are highly variable and somewhat unpredictable. These sheared rocks are finer grained than G3 units and are very hard. Similarly, mylonized gneiss is hard and generally not water productive.

Bedrock in the southern areas (Map Sheet 29) have been subjected to more tectonic disturbances, and consequently are more fractured; hence, the MY units in this area are typically much more productive than in other areas. Quartz veins in these southern areas are common, and when fractured they are not subjected to as much secondary plugging by weathering products, leading to higher hydraulic conductivity.

5.9.2 REGIONAL FAULT ZONES (FZ)

All rocks in Swaziland's stratigraphic succession have been affected by faulting to varying degrees. The faults trend predominantly in northerly, north-northeasterly or north-northwesterly directions. However, as the geology of Swaziland is structurally complex, all directions are possible (see Figure 23). In addition, the nature of the faulting in Swaziland varies. Thrust faults are common in the Greenstone Belt, while block faulting predominates in other areas.

Recognition of faulting within the softer or more deeply weathered rocks, such as the Karroo sediments and the Sabie River basalts, can be difficult. Even though a fault is recognized, this does not ensure that a productive groundwater zone exists. Sustainability of open fractures along fault planes is believed to be more likely in more rigid rocks, such as igneous and metamorphic rocks, than in relatively soft sediments where the fractures would tend to be squeezed shut. However, since faulting follows lines of structural weakness and provides avenues for the later emplacement of dykes, quartz veins, or other intrusions, the permeability that may have been present initially is often destroyed.

There are records of 91 boreholes in the FZ hydrogeologic unit. Of these boreholes, 70 have records of blown yields which range up to 20 L/s, and average 2.65 L/s (see Figure 38 and Table III). Not surprisingly, this is the highest average yield for all designated units. No boreholes yielded less than 0.01 L/s. The highest yielding boreholes (AE24-01 and AC23-02) both penetrated fractured bedrock at depths in excess of 20m below ground. The first water strike (2.9 L/s) in borehole AE24-01 was in a small fracture located at a depth of 24.4m below ground. The remaining yield was picked up in isolated zones, principally at the bottom of this 79.3m deep borehole.

Some faults are rendered impermeable by weathering products, clay gouge, or filling by dykes or quartz veins. Plugging by weathering products is particularly common in the shallower zones, often confining the highly permeable underlying fractured zone below (e.g. flowing artesian borehole AR35-01; Photo 23). Detailed investigations are necessary to properly evaluate the water-bearing possibilities, and to accurately site the borehole to intersect the fault at the desired depth. If detailed investigations are not possible, it is best to locate a borehole on the eastern side of a fault trace, as this is the dominant dip direction.

6. REGIONAL GROUNDWATER MOVEMENT

6.1 RECHARGE MECHANISMS

Groundwater recharge is an estimate of the percentage of mean annual precipitation that enters the sub-soil and ultimately percolates downward to the groundwater table. Recharge amounts are highly variable, ranging from zero to greater than 50%. Precipitation which does not recharge the groundwater table runs off directly to surface water courses or evaporates before infiltration.

There are many factors that affect the amount of precipitation reaching the water table and recharging the groundwater flow systems. Specific factors controlling recharge in Swaziland include:

i) Nature of near surface soils - higher permeability soils allow faster water percolation. Also, water holding capacity of the soil is important, especially in areas such as Swaziland where rainfall events are of short duration and are relatively infrequent.

ii) Frequency and duration of precipitation events.

iii) Shape and slope of ground surface - rainfall on steep slopes will tend to run off quickly as surface water, with little time available to allow for infiltration into the soil.

iv) Type and density of vegetative cover in the recharge areas - areas with thicker, more absorbent leaf structures and well developed root systems will temporarily trap the incoming rainfall, much of which will eventually evapotranspire back into the atmosphere.

In Swaziland, recharge rates are quite variable with a wide range of possibilities. High infiltration areas would include areas of fractured exposed rock with no vegetative cover, located in relatively flat terrain (Photos 24 and 18). Low infiltration areas would include steep sided, bare rock areas (Photos 6 and 17), and heavily cultivated loamy soil areas. High recharge areas are often very localized (for example the bed of a stream flowing over permeable alluvium); hence, estimates of regional amounts of recharge can only provide approximate regional averages.

In the Highveld areas, deeply weathered zones (saprolites) of variable permeability are common. Clay minerals often predominate near the base of the saprolite, which can impede groundwater infiltration (see Figure 34). In this case, a perched water table will form and, when located near surface in high relief areas, springs or seeps may occur. These seeps and springs may be large enough to act as localized groundwater storage zones, thus reducing the amount of recharge to the regional bedrock aquifer. A further consequence is that these discharge zones are prone to surface water erosion, and can result in the formation of dongas (Watson et al, 1984 and Watson, 1987), as shown in Photo 28.

6.2 FLOW PATHS

The principal pathways for groundwater movement in high relief areas are either through shallow colluvium and/or weathered shallow bedrock (see Figures 27 and 34). In lower relief areas where bedrock predominates, most groundwater occurs in fractures associated with faulting or jointing, and in deeper weathered zones along metamorphosed contacts (dykes, sills, etc.)

Because of the relatively discontinuous nature of even the regional fracture zones, there are no significant deep seated flow systems present in Swaziland. No evidence has been found to suggest that flow systems penetrating several hundreds of metres below ground surface and transmitting significant amounts of groundwater exist in Swaziland. Other studies, including geochemical evaluations of hot spring waters, have concluded that the flow systems are all of a localized nature (Section 6.3).

6.3 DISCHARGE ZONES

Discharge areas are located primarily in the river valleys, often where there is a change in hydrogeologic conditions of the bedrock and/or a change of slope along hillsides. Conditions that could result in groundwater discharge include:

a) presence of an impermeable barrier, such as a dolerite dyke

b) change of rock type (Photos 25, 26 and 27)

c) change in thickness of the permeable strata (Photos 28 and 29)

d) fault outcrop (Photo 30), or

e) sufficient groundwater inflow to exceed the storage capacity of the shallow aquifer.

Groundwater discharge areas can be categorized in declining order of magnitude as follows: springs, subaqueous zones, seeps, wet areas and mineral deposits. To date, over 300 discharge zones have been identified in Swaziland. Their locations are shown on the 1:250,000 scale hydrogeologic map. A summary of flow and chemistry data on selected discharge zones is given in Tables VI, VII and VIII. Typical discharge areas and brief descriptions are also presented in Photos 25 to 30. The significance of each type of discharge zone is presented in the following sections:

6.3.1 SPRINGS

Springs are located in areas where groundwater movement is such that a visible surface water flow can be seen. Springs may be permanent or ephemeral, and are often characterized by distinctive vegetation in and along the downstream channel.

Springs are most prolific in the Highveld (CIDA/WHO, 1981) and many have been developed for water supplies.

The most common type of springs in Swaziland are found in the lower third of the hill slopes (see Figure 27 and Photos 25 and 27) at geological contacts (Photos 25 and 26) and adjacent to dykes and fault/fracture zones (Photos 26 and 30). Accurate statistics on spring flows are not available; however, discharges of up to about 15 L/s were observed during the Project field program. Flows of up to about 60 L/s have been quoted by other sources, but these could not be confirmed. Spring water temperatures normally range between 20 and 30°C, and average about 27°C.

6.3.2 THERMAL SPRINGS

Some springs are much warmer than normal groundwater temperatures in Swaziland, and when temperatures exceed 35°C, they are considered to be thermal. The thermal springs of Swaziland have been studied for many tens of years, partly out of academic interest and often in the evaluation of long-term use as a tourist attraction. In one instance, the Royal Swaziland Hotel, located in Ezulwini (see location on Figure 5) was built around a thermal spring and operates a spa as a commercial venture.

Reports on thermal springs in Swaziland include those by Rindl (1932), Spargo (1965), Gevers (1965), Mazor et al (1974),Temperly (1975),Robins and Wilson (1978) and Robins and Bath (1979). Thermal groundwaters have also been found in deep fault zones in adjacent parts of the RSA (Wiess, 1938; Krige, 1939; and Kent, 1949).

Most of the 17 known thermal springs in Swaziland are located in the lower Highveld and Middleveld regions (see Figure 41). Discharges range from 0.2 L/s to about 8 L/s, and water temperatures range from 36°C to 52°C (see Tables VII and VIII). All springs appear to be associated with granitic and metamorphic bedrock (Photos 31 and 32).

It is probable that groundwater recharge in areas of the Highveld infiltrates to depths of a few hundreds of metres along a network of regional fractures or fault planes, picks up geothermal heat, then rises quickly to the surface as buoyant thermal water. These springs are rarely located near any of the well recognized fault or fracture zones; hence, it is suggested that thermal waters migrate laterally along shallower permeable zones before discharging to surface. Relatively low electrical conductivities and total dissolved solids (see Table VIII) indicate that spring groundwater residence times are relatively short.

Studies carried out by Robins and Bath (1979) and isotope analyses (Section 7.5) by Mazor, et al (1974) found that the maximum temperature reached along a typical flow path is about 120°C, supporting the theory of short residence times.

6.3.3 SEEPS

Seeps are similar to springs, with the exception that there is no recognizable channel conducting water away from the site. Seeps periodically dry up, creating different types of associated vegetation. Surface water movement from the area is sufficient to prevent any significant salts precipitation in the shallow soils.

Seeps are found in all four geographic regions of Swaziland; however, they are most common in the Middleveld. The presence of Mhukhiwa trees (related to the fig tree) is a good indication of seeps and wet areas in the Highveld and Middleveld.

6.3.4 WET AREAS

Wet areas are defined as areas where the water table is shallow enough to be reached by vegetations which are known to evapotranspire a significant amount of water (hydrophytes).

Wet areas can be found in all four geographic regions of Swaziland; however, they are most common in the Lowveld. The presence of Inkhanyakudze trees is a good indication of wet areas in the Lowveld. *Imperata cylindrica, Typha capensis* and several other hydrophytes are found in non-calcareous wetland areas, and *Cyatheea dregei* is found in the Highveld bottom lands which are rich in organic matter.

6.3.5 MINERAL ZONES

Mineral zones will develop wherever groundwater discharge is moderately low, evaporation rates are high, dissolved salts in the groundwater are moderate to high, and where surface runoff is insignificant. As such, these zones are unique and not common in Swaziland. The most common deposit is ferricrete, an iron rich oxide which has a hard slaggy appearance, found in some areas of the Middleveld, Lowveld and Lebombo Hills. Localized zones of calcrete are also occasionally found.

6.4 GROUNDWATER RECHARGE AND WATER BALANCES

The amount of water entering any given aquifer is equal to that which is released either from natural discharge or pumped from boreholes. Average water levels will decline if discharge is greater than recharge. Estimates of the quantity of water entering or leaving an aquifer are difficult to make, even if the extent of the aquifer is well defined. Where aquifers are relatively thin and not well defined, such as in Swaziland, estimating quantities of recharge is very difficult. However, there are a number of methods that provide useful approximations of groundwater recharge. These have been applied to selected areas of Swaziland, and are presented in the following.

6.4.1 WATER BALANCE METHOD

The conventional method of estimating groundwater recharge uses the following simple formula:

$$P = E + R + S$$

Where:

P = precipitation

E = actual evapotranspiration

R = surface water runoff

S = change in soil moisture in storage

If the soil is already saturated when a precipitation event occurs, then the excess moisture will migrate down to the water table.

Actual evapotranspiration can be estimated by a number of methods, including Penman (1954), and Thornthwaite (1948), by using the measured pan evaporation and then applying a reduction factor. The application of these methods is referred to in published articles on case histories, such as Rushton and Ward (1979) and Houston (1982).

Estimates of total annual precipitation infiltrating down to the water table in Swaziland were calculated using the Thornthwaite method (Appendix G). Calculated infiltration ranges between 0.5% and 15%, with higher values found at increased elevations. These infiltration rates were calculated to generate a volume of groundwater between 0.05 and 5 L/s/km^2.

6.4.2 WATER TABLE RESPONSE METHOD

Hydrographs of groundwater levels in selected boreholes, along with daily rainfall histograms, are presented in Appendix F. These records show that there is generally a response to infiltration rainfall within a few months of the onset of each wet season. The degree of the response varies from little to nothing in the discharge areas, to relatively significant (a few metres) in the recharge areas.

Comparison of precipitation amounts with corresponding water levels in selected monitoring boreholes in each topographic region was carried out (Table IX). Based on these data, the estimated recharge amount is between 1% and 12 % of the average annual rainfall for a particular area. As predicted by the water table response method, the highest recharge was found at borehole X0801, located in the Greenstone hydrogeologic unit (GB) in the Highveld (Appendix G).

6.4.3 STREAM BASEFLOW METHOD

Streamflows from gauged drainage basins were reviewed with particular emphasis on the latter part of the dry season (August to September). At this time of year, the flow is considered to be primarily provided by natural groundwater discharge (baseflow). Baseflows provide an assessment of approximate annual groundwater recharge fluxes when divided by the basin area (L/s/km^2). These fluxes are then compared with average annual rainfall flux onto the basin, and from this, groundwater recharge is estimated. Groundwater recharge calculated using this method ranges between about 0.5% and 17% of average annual rainfall for particular areas (Appendix G).

As an example, baseflow discharges from rivers draining the Greenstone Belt area in the northwest corner of Swaziland are relatively high all year round, confirming the presence of extensive unconfined aquifers. The upper portion of the Mbuluzi River drains an area underlain by both GB and G3 units, in about equal portion. September low flows recorded at the former leper colony (station 4 on Figure 21) are typically between about 0.4 and 1.1m^3/s (average for 1960-81 was 0.8 L/s). The 0.4m^3/s flow (i.e. baseflow) is approximately 6.8% of the annual rainfall on the catchment. As this flow followed a summer of almost no rain and consequently no surface runoff, it likely represents the total annual groundwater recharge within the basin. These results are consistent with studies in other areas of southern Africa, such as work carried out by Houston (1982) in Zambia.

6.4.4 WELL FIELD DATA ASSESSMENT

Some information on average groundwater abstraction rates is available for the well fields operated by the Royal Swazi Sun Hotels and National Textile Ltd., both located in the Middleveld. A summary of this information and the results of the assessment are given below.

Royal Swazi Sun Hotel Complex

Up to five boreholes, all located in hydrogeologic unit GW, have been pumped for over ten years at a combined rate of about 9 L/s (24 hour basis). The well field (incorporating boreholes AF14-42, AF14-46 and AF15-31) is located in the Ezulwini Valley, which has an effective recharge area of about 1.5 km^2 and an average annual precipitation of approximately 1,000mm.

Thus, if all the recharge flux supplying the well field is assumed to be derived from precipitation (Thornthwaite method), then the flux would be 6 L/s/km^2. This is equivalent to 19% of the annual rainfall. This figure appears to be slightly high, suggesting that irrigation of the nearby golf course may be supplementing the recharge.

National Textile Ltd.

Three production boreholes (AJ19-33, AJ19-34 and AJ19-35) are located on a property in Matsapha. They have reportedly delivered a combined yield of about 9 L/s on a relatively steady basis for over two years, with no significant drawdown in the weathered granodiorite (GD\WE) aquifer. The estimated recharge area is about 1.9 km^2, and the average annual precipitation is about 940mm. Thus, the recharge flux is 4.7 L/s/km^2, or equivalent to 16% of the annual rainfall. However, some of the recharge may have been induced from the nearby Lusushwana River.

A detailed hydrogeological study of each of the two areas summarized would be required before a more precise estimate of groundwater recharge can be made.

7. HYDROGEOCHEMISTRY

7.1 REGIONAL TRENDS

The chemical composition of Swaziland groundwaters is influenced more by climatological and topographic factors than by the mineral composition of the geological units. In general, groundwater quality is very good when compared with World Health Organization (WHO) guidelines, particularly in the Highveld and Lebombo regions. Groundwater typically evolves from a calcium-magnesium-bicarbonate type in the recharge areas, towards a sodium-chloride type water in the discharge areas. This is a common phenomenon, due to exchange of dominant ions during groundwater migration.

In the Highveld areas, electrical conductivities (EC) are relatively low, generally being less than 250 µS/cm (see Figure 42). In contrast, it can be seen that in the Lowveld, where evapotranspiration rates are high and the rate of groundwater flushing is low, groundwaters tend to become relatively salty with EC values up to 4,000 µS/cm, and total dissolved solids (TDS) concentrations in excess of 1,500 mg/L. A histogram summarizing the EC of all groundwaters sampled is shown in Figure 43. Chemical analyses of groundwater samples indicate a direct relationship between chloride, sodium and EC in Swaziland groundwaters (see Figure 44). Thus, geographic distribution of sodium (and chloride) is similar to that of electrical conductivity (see Figures 45 and 54).

Chemical analyses of groundwaters in Swaziland also reveal some other trends. Figure 46 shows that major ion concentrations are highest in the sedimentary hydrogeologic units, and lowest in the granitic hydrogeologic units. When chemistry results are compared for all the major hydrogeologic unit types, the relative proportions of the major ions in the different units are similar, with bicarbonate having the highest concentration and magnesium having the lowest.

7.2 GEOCHEMISTRY BY UNIT TYPE

7.2.1 GRANITIC UNITS

Geochemical trends in the granitic hydrogeologic units are similar to other types located in similar physiographic areas, i.e. an evolution of calcium-bicarbonate type groundwater in the wetter recharge areas on higher hills (areas of low EC), towards a sodium-bicarbonate type water with elevated chloride and sulphate in the low-lying discharge areas (see Figure 47). Electrical conductivity values are variable, ranging from 20 to 4,000 µS/cm. The higher values are generally for the granodiorites, principally those located in the lower Middleveld.

7.2.2 METAMORPHIC UNITS

Geochemical trends in the metamorphic hydrogeologic units are similar to those in granitic units, as illustrated in Figure 48. Electrical conductivity values range from 25 to 1,600 µS/cm (see Figure 49). The highest values are for the dolerite-diabase unit (DO) encountered in deep boreholes located principally in the lower topographic regions of Swaziland.

7.2.3 VOLCANIC UNITS

Electrical conductivity values for volcanic hydrogeologic units with any significant amount of boreholes drilled into them ranged from 120 to 3,000 µS/cm (see Figure 50). The highest average EC values were found in the massive basalt unit (BA), which includes weathered basalts (BA/WE) in the lower topographic regions of Swaziland. Average maximum EC values for basalts with numerous dykes (BD) and the Lebombo Rhyolites (LR) are approximately 13% and 56% lower, respectively, than for BA.

Highly mineralized basaltic groundwaters were typically found in broad, flat, low-lying areas with low rainfall (i.e. the Lowveld). In these areas, infiltrated water is restricted from flushing out the salts dissolved from the bedrock. Conversely, the BD and LR volcanic rocks are often located at somewhat higher elevations in recharge areas, thus explaining the lower electrical conductivity values.

Geochemical trends in the volcanic hydrogeologic units are similar to granitic and metamorphic units, with a slightly stronger sulphate trend noted (see Figure 51).

7.2.4 SEDIMENTARY UNITS

Electrical conductivity values range from 180 to 4,000 µS/cm (see Figure 50). The highest values were obtained for the Karroo Ecca unit (KE), which was encountered in deep boreholes located in the Lowveld. Geochemical trends in the sedimentary hydrogeologic units are similar to those of the hydrogeologic units discussed above (see Figure 52).

7.3 NITRATE IN GROUNDWATER

Nitrate concentrations ranged up to about 38 mg/L as nitrogen (mg/L-N) and averaged 3.4 mg/L (see Table X). The WHO has set a 10 mg/L-N limit for nitrate. Concentrations in excess of this value could result in infantile methemoglobinemia, a condition where the oxygen carrying capacity of the blood is reduced, and in extreme cases has been known to cause death. There is also some evidence to suggest that ingesting significant quantities of high nitrate water may increase the chances of cancer.

There is no simple relationship of nitrate concentrations with hydrogeologic unit type in Swaziland (see Figure 53). However, there is a strong correlation with total dissolved solids, suggesting that nitrate concentrations will be highest in areas where the rate of flushing is lowest and evapotranspiration is highest. The most probable source for the nitrogen in Swaziland groundwaters is from fixation of atmospheric nitrogen in the soils around the leguminous trees and shrubs of the Acacia species, which are most common in the Lowveld area.

7.4 FLUORIDE IN GROUNDWATER

Fluoride concentrations in Swaziland groundwaters were found at concentrations as high as 18.4 mg/L (see Table X). The distribution of fluoride throughout Swaziland is indicated in Figure 54 and, as can be seen, there are a number of areas where concentrations exceed 2 mg/L. These areas are located mostly in the Middleveld and Highveld, with some in the Lebombo escarpment area.

Fluoride concentrations up to 1 mg/L in drinking water are considered very beneficial in the control of dental cavities. However, concentrations above 3.5 mg/L may result in mottling of teeth. Many health organizations have adopted a 1.5 mg/L safe limit for fluoride in drinking water, although the US EPA has recently been considering revising the limit to 2 mg/L.

There does not seem to be any direct correlation between fluoride concentration and hydrogeologic unit type. Fluorine is a relatively abundant earth mineral (about 0.04% of the earth's crust) but, as it is relatively insoluble in water, concentrations in groundwaters in many parts of the world are typically less than 0.5 mg/L. Fluorspar deposits have been identified in a number areas of Swaziland, many of which are located in the south central part of the country (Urie, 1964). To date, there is no evidence of a correlation between these mineral deposits and elevated fluoride in groundwater.

In a study carried out in Rajasthan, India (Handa, 1975), it was found that there was a good correlation between nitrate and fluoride concentrations in groundwater. A complex theory involving solution, evaporation and base exchange mechanisms was put forward to explain the genesis of these groundwaters. Thermodynamic theory predicts that fluoride concentrations would be lower in areas where calcium concentrations are highest. Similar relationships were also found in Swaziland.

Anomalous fluoride concentrations have been observed in Swaziland. For example, the Luyengo-Ntondozi area serves as a sample case history of one localized occurrence. Concentrations up to 7.6 mg/L were observed in a number of springs and boreholes in a narrow zone approximately 300m wide, and trending northwest-southeast in this area (see Figure 55). The area is underlain by migmatized gneiss of the Ngwane Gneiss (GW), the Usutu Granodiorite (GD), granophyres and gabbros belonging to the Usushwana Complex (UC) and the Mswati Granite (G5). It is postulated that the high fluoride occurrence may be confined to a linear zone, related to the episode of intrusion of the gabbro.

7.5 NATURAL ISOTOPE STUDIES

7.5.1 CONCEPTS

Environmental isotopes in groundwater investigations have two useful purposes; as tracers to identify the origin and history of groundwaters; and as dating tools to provide estimates of mean groundwater residence or circulation times. These techniques have been used in southern Africa (Vogel and Van Urk 1975) and in other parts of the world (Craig, $1961_{(b)}$, Paces 1975; Truesdell and Fournier, 1977; Clark and Fontes, 1989) as an aid in evaluating groundwater flow systems.

Studies of groundwater origins primarily rely on the use of the stable isotopes in water, ^{18}O (oxygen-18) and ^{2}H (deuterium), as well as those present in dissolved carbonate and sulphate (^{13}C and ^{34}S). The stable isotope contents in precipitation and in groundwaters during recharge vary according to the thermodynamic processes which relate to the historical changes of state imposed on the water. These temperature dependent processes will impart a fractionation effect on the water mass, effectively partitioning the heavy isotopes into one of the two phases of the reaction (during the change of state). The altitude effect is one such process, where precipitation occurring at higher elevations tends to have relatively less heavy isotopes than precipitation at lower elevations. Thus, in a given region, groundwater with a higher heavy isotope concentration would likely have entered the ground at a lower elevation than groundwater with a lower concentration of heavy natural isotopes.

Estimates of groundwater circulation time rely on the use of the natural radioactive isotopes tritium (^{3}H) and radiocarbon (^{14}C), and are now routinely applied in hydrogeological studies. Radioactive decay from the initial activity in the recharge area to the measured activity in the groundwater sample can be an indication of the "age" of the sample. In practice, consideration of the geochemical processes and mixing of groundwater flow systems must be made in order to correct for gains or losses not related to the natural decay.

7.5.2 ISOTOPE DATA FOR SWAZILAND

Analyses of naturally occurring isotopes in Swaziland groundwaters and surface waters have been obtained from two principal sources (PAEL, $1992_{(a)}$ and Mazor et al, 1974). The former source is a report prepared in conjunction with the DGSM/CIDA sponsored Groundwater Survey Project in which 55 samples of groundwater, surface water and some rainfall were analyzed for ^{18}O and ^{2}H, and fifteen were also analyzed for ^{3}H. The older study concentrated on analysis of thermal waters. Both sets of data are plotted on Figure 56.

7.5.3 ISOTOPES IN PRECIPITATION AND SURFACE WATER RUNOFF

7.5.3.1 Stable Isotopes

In order to fully characterize recharge inputs to groundwater flow systems, precipitation and surfacé water samples should ideally be collected from a variety of elevations at various times throughout the year. Unfortunately, this was not possible during the isotope study carried out in 1988. However, four samples of rainfall and seventeen samples of surface runoff were collected and analyzed. These data are represented as purple triangles and orange dots for rainfall and surface runoff, respectively, on the three isotope plots (deuterium vs oxygen-18, on Figure 56, oxygen-18 vs elevation on Figure 57 and deuterium vs elevation on Figure 58).

An examination of Figure 56 suggests that precipitation, as reflected by sampled rainfall and creek stations, rarely falls on the global meteoric water line (GMWL) as defined by Craig ($1961_{(a)}$). In general, the precipitation in this region appears to have higher deuterium concentrations than suggested by the GMWL. A deuterium excess of about 10 $^{0}/_{00}$ relative to the GMWL is not uncommon for continental precipitation in the southern hemisphere of Australia and central Africa (Dansgaard, 1964). Thus, based on these considerations, local meteoric water in Swaziland is best approximated by the Swaziland Meteoric Water Line (SMWL) indicated on Figure 56. The SMWL has the following formula:

$$^{2}H = 7.8 \quad ^{18}O + 14$$

Samples of Mbabane rainfall were collected in September and December 1988, and while both sets of oxygen-18 and deuterium isotope data plot close to the SMWL, they are widely separated. This is likely a result of a complex mixing of atmospheric water vapour prior to the precipitation events. As most groundwater (represented by wells and springs on Figure 56) is isotopically heavier than rainfall represented by the SMWL (i.e. located below and right of the line), it is concluded that, in most regions of Swaziland, isotopically light rainfall does not contribute much to groundwater recharge.

Concentrations of oxygen-18 and deuterium were plotted against sampling elevations for all samples collected (seeFigures 57 and 58). Instead of the classic linear (alpine) relationship between each isotope value and elevation, there is a high degree of scatter. This scatter is likely due to samples being collected at different times of the year, and the fact that some evaporation of the precipitation has taken place in either the soil or at the ground surface. Creek samples (zone 1 on Figures 57 and 58) plot to the right of most of the spring and well samples. Many of the creek samples (including the Lusutfu River) are located in the Lowveld area, and hence plot at elevations less than 500m and towards the heavy isotope, right side of the two graphs.

7.5.3.2 Tritium in Precipitation

The short half-life of tritium, 12.43 years, makes the tritium radio isotope ideal for the identification of young groundwaters with regular recharge. Natural tritium is generated in the upper atmosphere by cosmic neutron collisions with the common nitrogen isotope (^{14}N) in the atmosphere, which produces ^{12}C and ^{3}H. Natural production is roughly 5 to 15 TU (1 TU = 1 ^{3}H per 1,010 ^{1}H), although nuclear weapons testing in the atmosphere during the 1950's and 1960's raised tritium concentrations by a few orders of magnitude. Currently, atmospheric concentrations are close to natural levels, as a result of mixing with ocean water and minor amounts of radioactive decay.

No long term records exist for tritium in precipitation for Swaziland, although data for surface runoff from this study and from Mazor (1974) are instructive. In 1972, tritium levels in runoff were in the order of 50 TU (Mazor et al, 1974) and by 1989 had dropped to about 7 TU (PAEL, $1992_{(a)}$).

7.5.4 EVAPORATION EFFECTS IN RUNOFF WATER

In most arid and semi-arid climates, runoff and groundwater recharge are accompanied by a certain degree of evaporation. Due to the difference in mass ratios in the, water molecule for $^{1}H_2{}^{18}O$ (mass 20) and $^{1}H^{2}H^{16}O$ (mass 19), the non-equilibrium or kinetic isotope effects which occur during evaporation favour the concentration of oxygen-18 in the water phase. This effect can be seen on the deuterium vs oxygen-18 plot (see Figure 56) as a positive departure from the local meteoric water line, and typically plots along a line with a slope of between 2 and 5 (Fontes, 1980). Evaporation effects are useful in characterizing recharge processes and environments. Clark (1987) developed a basis for evaluating the evaporation effects in the groundwater recharge areas in Oman, and used these analyses for evaluation of groundwater recharge.

The surface water samples collected during the Project clearly show a evaporation effect, and plot on a Local Water Evaporitic Line (LWEL; see Figure 56) with a slope of approximately 1:5. These data are useful in providing an indication of the probable history of the surface water.

7.5.5 STABLE ISOTOPE DATA FOR GROUNDWATERS

7.5.5.1 Stable Isotopes

Plots of oxygen-18 versus deuterium values for water samples obtained from boreholes, springs and thermal waters, as well as rain and surface waters, are presented in Figure 56.

Many groundwater samples plot to the right of the SMWL, and it is apparent that these groundwaters have experienced a degree of evaporation prior to infiltrating into the ground.

As indicated earlier, the plot of oxygen-18 vs elevation (see Figure 57) did not clearly show an alpine effect. However, back extrapolation to the SMWL using the slope of the Local Water Evaporitic Lines (LWEL) established above with surface runoff waters, can provide an indication of the probable original $^{18}O/^{2}H$ content in the precipitation. This value could then be used as a rough indication of the elevation of the recharge area. A more comprehensive set of rainfall data would be required for a more accurate estimate of recharge elevations.

As would be expected, the thermal springs plot in left to middle of the isotope scales, suggesting that the water had primarily entered the subsurface where precipitation was relatively light, i.e. at higher elevations.

The groundwaters in the Lowveld region along the western border of the Lebombo Mountains are relatively depleted in stable isotopes. Some samples show evidence of strong evaporation. Precipitation in the Lebombo Mountains and subsequent discharge to the Lowveld is a likely origin of these groundwaters, although some recharge likely takes place in the form of infiltrating surface water runoff in the foot of these mountains.

By contrast, the groundwaters sampled from the northern Middleveld region in the Mbuluzi and Komati River drainage systems are less depleted in stable isotopes, and plot above the Lowveld group on Figure 58. Recharge to these groundwaters most likely originates as a mix of Middleveld and Highveld precipitation. The evaporation seen in many of the samples suggests that infiltration from drainage channels, after a significant period of surface residence, is the main recharge mechanism. By contrast, some samples show very little evaporation, suggesting direct infiltration to the subsurface in the upland areas.

The thermal spring waters sampled by Mazor et al (1974) are isotopically very different from the samples collected in this study (see Figure 58). Their high temperature, low ^{3}H contents and low ^{14}C activities all clearly indicate deep circulation and a long subsurface residence time. Accordingly, the most likely recharge environment is in the highlands of the Drakensberg Range to the west in South Africa, which is the highest area in the catchment basins of western Swaziland. The position of these samples well above the SMWL indicates that a different meteoric water line may dominate in this area.

7.5.5.2 Tritium In Groundwaters

The tritium content in groundwaters can be used to indicate the relative subsurface residence time. High levels (greater than 10 to 20 TU) indicate a component of recharge from either the 1960's or the 1970's, whereas low levels (less than 5 to 10 TU) suggest very modern (i.e. recent) recharge and a relatively short subsurface circulation time. Values below detection (less than 0.8 TU) indicate that the groundwater was recharged prior to the beginning of nuclear weapons testing in 1952, and thus suggests a mean subsurface time of greater than about 40 years. Very small amounts of tritium (1 to 2 TU) generally suggest a mixture of older groundwaters with shallow, young groundwaters.

The concentrations of tritium in 18 samples of Swaziland groundwater were collected between 1988-89 and analyzed values ranged from a high of 6.4 TU to less than detection. Most groundwaters had low tritium values, suggesting that they contained a relatively significant component of recent rainfall recharge. However, as the wells (boreholes) were between 50 to 100m deep with significant lengths of uncased hole in fractured and/or leached bedrock, groundwater could enter the hole at a range of depths. Thus, it is likely that the well samples included water from more than one flow system, and that the tritium values represented a mix of both relatively young (modern) and old (greater than 40 years) waters.

Borehole samples from the Lowveld areas show a clear relationship between increasing tritium contents and increasing ^{18}O (PAEL, $1992_{(a)}$).

7.5.6 SUMMARY OF FINDINGS FROM ISOTOPE STUDIES

Groundwater flow systems are relatively slow moving and, with few exceptions, will follow topographic contours. Groundwaters in the Lowveld area of eastern Swaziland show some evidence of origin in the Lebombo Mountains located to the east, where recharge into two flow systems occurs. These include:

a) a shallow, relatively young (5 to 10 year) groundwater flow system, which is recharged by infiltrating evaporated surface water, and

b) deeper and older (over 40 years) groundwaters, which were recharged by direct infiltration at higher elevations (in the Lebombo Mountains).

Groundwaters in the Middleveld and north central Swaziland show similar evidence of a two component system:

a) five to ten year old evaporated groundwater, which originated from infiltrating surface water runoff from the west, and

b) a deeper groundwater flow (older than 40 years old), which was recharged by direct infiltration in the adjacent Highveld or upper Middleveld areas.

8. GROUNDWATER DEVELOPMENT

8.1 BOREHOLE YIELDS AND DEVELOPMENT POTENTIAL

Blown yields from boreholes in individual hydrogeologic units have been cited throughout this report, as much of the borehole yield data has been compiled in this manner. However, there are also records of data for about 200 constant rate aquifer tests, all but six of which were conducted during the Groundwater Survey Project. Comparisons between blown yields and pump test flow rates indicate that the testing rates are about 50% of the blown yields. However, this data is not entirely representative, as about 40% of the pump tests were not run at the full capacity of the borehole, due to limitations imposed by pump capacity and testing logistics. Furthermore, based on experience from other areas, the short term blown yields are rarely sustained when a borehole is pumped on a continued 24 hour basis, unless the aquifer is hydraulically connected to a nearby surface water body such as a lake or river.

Long term yields for each borehole tested were estimated using a simple technique developed in Canada, referred to as the Q_{20} method. This method calculates a sustainable (i.e. long term) yield for 20 years of pumping, and takes into account the apparent aquifer transmissivity at the end of each aquifer pump test. A comparison between calculated yields and blown yields indicates that the long term yields are equal to or greater than blown yields. However, as water-bearing zones in Swaziland are normally of limited extent, these Q_{20} values can only be regarded as optimistic projections of "safe" yields. Actual safe yields for a particular borehole in fractured bedrock require detailed site specific analyses for each borehole, which is beyond the scope of the Groundwater Survey Project.

Based on a limited number of detailed analyses, both on testing data from Project boreholes and data from other previously existing boreholes with well documented abstraction rates, it appears that the relationships given above are reasonable for most areas.

Another approach to assessing long term yields is to assume that the yield of boreholes is limited by recharge, and hence potential average borehole yields can be determined by back analysis. This method assumes that the aquifer transmissivity and hydraulics of each well will be sufficient to provide the yields determined by this method. The long term yield is confirmed by comparison with actual blown yields, incorporating an appropriate reduction factor.

Calculations for yields in the four principal physiographic regions, using this method, are set out in Table XI. This approach suggests that the potential total groundwater recharge in Swaziland is in the range of about 15,000 to 25,000 L/s, with an average of about 20,400 L/s. This compares with an estimated existing borehole production capability of 1,313 L/s, equivalent to about 6.4% of the potential recharge. It should be noted that many of the existing boreholes do not have pumps installed, and few have electric pumps which are capable of pumping at rates equivalent to the borehole's full capacity. Hence, current actual groundwater usage is probably less than 300 L/s, when calculated on a steady state basis.

As would be expected, there are relatively few boreholes in the relatively inaccessible Highveld, where the highest groundwater potential exists. However, a large number of springs have been developed by the Rural Water Supply Board for community use in this region. By contrast, the Lowveld is an area where potential recharge is lowest and the need for groundwater highest. Boreholes presently utilize about 42% of the estimated potential recharge in the Lowveld.

It should be stressed that the figures presented in Table XI are only approximate, and are presented solely for the purpose of providing preliminary estimates of yields for planning purposes. More detailed studies of selected areas are required before annual recharge and borehole yield quantities can be better refined.

8.2 CONJUNCTIVE DEVELOPMENT WITH SURFACE WATER

As indicated throughout this report, there is considerable interaction between surface water runoff and the groundwater resources of Swaziland. This applies to aquifers discharging into surface water bodies, and vice versa. The latter is particularly relevant in areas where the drawdown cones around pumping boreholes have extended out to, and become hydraulically connected with, nearby surface water bodies. This induced infiltration of water from the rivers or water storage reservoir beds into the aquifer allows relatively higher sustainable pumping rates of good quality water.

In areas where there is an increasing number of high yielding boreholes which are hydraulically connected to a nearby river, the dry season flows in the river may gradually diminish, and water rights of downstream users would be affected.

As more information on hydrogeologic units and groundwater usage becomes available, it will become increasingly more feasible to predict potential impacts on surface water flows, and hence enable controlled development of all water resources. However, as a minimum, this type of controlled development will likely require the administrative and legal framework that can only be provided by the proposed National Water Authority.

8.3 ADMINISTRATION AND CONTROL OF WATER RESOURCES

Development of surface water and groundwaters in Swaziland will require careful planning and some form of administrative control in the future (PAEL, 1987). These controls will be necessary to minimize conflicts, promote aquifer protection, and make the best use of the available resources.

While it is almost universally accepted that no one can have ownership of water flowing in a stream, a lake or in the ground under their property, owning the right to use the water for normal purposes is different. It is traditional in some countries, including Swaziland, that the owner of land bordering on a stream has the right to use water from the stream on his lands for such purposes as stock watering or irrigation.

If a person owns land on one bank of a stream, under "Riparian Rights" he may use half the water. If he owns land on both banks, he may use all the water in the stream, even if this deprives a landowner downstream of all his water. These rights are an integral part of the land rights of Swaziland, and do not depend on use or claim. Riparian rights are inconsistent with the proper planning or control of water resources, and have been abolished in many countries in favour of permit systems.

The simplest way to control use, and thus allow for proper planning for the maximum beneficial use of the water resources, is to require users to obtain a permit for a specific quantity of water, be it above or below the ground surface. Thus, an owner of riparian land would only be permitted to use a stated quantity of water, rather than a consistent fraction of all water. Such a permit can easily be adapted to apportion different quantities of water at different times of the year to facilitate proper water resource planning.

As discussed in the report entitled "Establishment of Swaziland National Water Authority" (PAEL, 1990), water use in Swaziland is controlled by the legislation set out in the 1967 Water Act. This act initially appears to have preserved riparian rights but, if the Government declares an area to be a "Water Control Area", the right to use water is transferred to the Government, who may then grant permits to water users. Existing users may convert their prior use to a permitted use.

The new draft water control legislation, which was finalized in 1990 by a GoS steering committee with the assistance of CIDA's executing agency (PAEL, 1990), makes it clear that riparian rights, as such, should be abolished. It appears that practically the whole country has been included in Water Control Areas under the 1967 Water Act. This means that riparian rights have in reality already disappeared, but the new draft Act makes this clear. The new draft legislation gives each user the absolute right to a permit, provided an application is made in time and that evidence of existing use is provided. Many small water users, however, would also be exempted from the need for permits, especially for low rates of abstraction.

The draft Act provides for the administration of water resources under a National Water Authority (NWA). Provisions in the present Act are continued unless they are no longer required, but in many cases the wording is simplified and reliance is placed on regulations.

The NWA will be a corporate body established by legislation, liable in its own name, and responsible for carrying out those functions prescribed by its legislation. It will be composed of senior people drawn from those GoS Ministries and agencies having a substantial interest in the water sector, and private sector water users. Execution of NWA policies will be undertaken by those agencies to which the policy is directed, and not by the NWA itself.

The NWA will be responsible for setting water sector policy and ensuring that such policy is carried out. In order to formulate meaningful policies, the NWA will require technical information. This will be provided either by the departments and agencies of the Ministry of Natural Resources, Land Use and Energy having the necessary expertise, or by task forces established with expertise drawn from those agencies, other Ministries and consultants.

In this proposed water control legislation, groundwater will also be brought under control, and permits will be required from the DGSM before boreholes are drilled and high rates of abstraction are allowed. Permittees will also be required to submit data on boreholes and yields to the DGSM. Because water quality is also important, the draft provides for the control of pollution by the requirement for a permit to discharge wastes onto the ground surface.

The contents of a draft regulation for groundwater is presented in Appendix B.

8.4 FUTURE STUDIES

As implied throughout this report, the process of surveying a resource that cannot be seen, such as groundwater, should always be regarded as an ongoing task, subject to available funds and anticipated future water needs. In the following, a few activities that could be carried out in the short to intermediate term have been identified for consideration.

a) More detailed assessments of hydrogeology of areas where groundwater usage is high are warranted, such as in the Ezulwini Valley, Malkerns and Matsapha areas. These evaluations should include drilling of production wells in known high yielding areas, conducting five day duration constant rate pumping tests, establishing additional groundwater monitoring wells, conducting computer simulations of water level responses and flow systems, and developing hydrogeologic water balances for selected areas with readily defined boundaries.

b) Collecting background information on potential contaminant sources in areas underlain by unconfined aquifers, installing monitoring wells, collecting water samples and conducting analyses of indicator parameters that may provide evidence of groundwater contamination. Potential contaminant sources could include chemical and fuel oil tanks, landfills, agricultural operations, etc.

c) Collect additional, and perhaps more accurate, low flow data (possibly using a pigmy flow meter) in selected small river basins during the late summer period.

d) Complete the survey of all major springs in Swaziland. This should include a re-survey of many of the UNDP spring survey sites.

e) Review and further refine the principal hydrogeologic units in Swaziland. If possible, the twenty-four principal units described in this report should be consolidated into a smaller number of units, with a suitable number of sub-units.

f) Further investigate the potential for regional scale groundwater movement along north-west trending lineaments, which extend from west of Bunya to Mhlosheni.

9. CONCLUSIONS AND RECOMMENDATIONS

9.1 GROUNDWATER RESOURCE POTENTIAL

The groundwater resources of Swaziland are substantial and have potential for significant exploitation, particularly in the Middleveld and Highveld areas. It is estimated that the total potential groundwater resource is equivalent to a sustained flow in the order of 21 cubic metres per second (21,000 L/s). To date, only about 6% of this potential has been tapped by over 1,400 boreholes. About 946 of these boreholes have information on yields, which range up to 20 L/s and average about 1.4 L/s.

With the establishment of the NWA, and improved reporting requirements, more information on borehole lithology and yields will expand the database on groundwater resources. This will allow the full potential of these resources, which is significant, to be utilized. Systematic and scientific methods developed during the Groundwater Survey Project should continue to be implemented.

9.2 PRODUCTIVE HYDROGEOLOGIC UNITS

The most productive hydrogeologic units in Swaziland are the Greenstone Belt (GB), Mozaan Group (MZ), Weathered Basalts (BA/WE) and Fault Zones (FZ), all of which have average borehole blown yields in excess of 2 L/s. Yields of up to 10 L/s are possible from fractured quartzites of the Mozaan Group. With the exception of Weathered Basalt, these units are principally located in the Highveld area of Swaziland.

Basaltic aquifers exhibit relatively high transmissivity in topographically low areas, and/or along baked contacts of dolerite intrusions. The Manyoneneni Aquifer, located in the southern Lowveld, consists of deeply weathered basalts and covers a large area in which boreholes may be sited without sophisticated siting techniques. Short-term borehole yields of up to 6 L/s are possible in selected areas of the Lowveld. Although boreholes located in basalts of the topographically high regions of Swaziland generally tend to have low yields, a regional fault which passes through Siteki provides a good yielding aquifer within the Lebombo Rhyolites (LR) and the Sabie River Basalt units (BA).

In terms of sedimentary units, borehole yields of up to 4 L/s were obtained from Karroo Nkondolo Group sediments (KN) on Map Sheets 4 and 8. Substantial yields are also feasible from screened boreholes completed in alluvium (AL), located along the Komati River and similar areas in the lower Middleveld.

Coarse-grained dolerite sills or dykes (DO) may form aquifers where they are highly weathered along their contact zone, or within the dyke or sill itself. Dolerite inliers located in basalts are usually good aquifers and capable of sustaining domestic demands. Dolerite inliers in the Karroo sediments, however, are generally not suitable for groundwater development.

Fault zones (FZ) form good aquifers and southwest-northeast trending faults, which traverse the strike of the majority of structures, tend to be most the most productive. One borehole located in a regional fault zone on Map Sheet 12 yielded 20 L/s.

Granodiorites on Sheets 11 and 12 around Mbabane and Manzini have been consistently high-yielding, averaging almost 2 L/s. The weathered granodiorite in the Malkerns valley has particularly good potential for further development. A threefold increase in borehole yield can be obtained if drilling is conducted where granodiorites are interlayered with amphibolites or serpentinites, or intersected by dolerite, diorite, or pegmatite dykes.

Where gneiss units are interlayered with amphibolites and cut by pegmatite veins, they will generally form useful aquifers, and can yield up to 12 L/s with a properly located borehole. However, in massive gneisses,these units are generally non-productive, unless boreholes are drilled close to small intrusive bodies. Gneiss units can also be productive if they are fractured or weathered; however, this is relatively rare.

For the purpose of this study, the water-bearing units of Swaziland were tentatively divided into twenty-four major hydrogeologic units with many sub-units. Because of the complexity of the various water-bearing units, development will require continued efforts to utilize all available methods for exploration, abstraction and management. Further research and refinement of these units is recommended.

9.3 SUSTAINABLE BOREHOLE YIELDS

Long term borehole yields depend on a number of factors, including permeability of the strata, geographic location, sources of recharge and the number of boreholes abstracting water from the same zone. Long term yield of each borehole could decline to yields of half that of the initial blown yield. For example, a borehole with an initial blown yield of 20 L/s might decline to a steady state flow of less than 10 L/s. Therefore, it may be more appropriate to determine sustainable yields based on recharge. It is estimated that groundwater recharge ranges between about 0.5 and 15% of average annual rainfall in any particular basin area. This represents recharge fluxes of between about 0.05 and 5 L/s/km^2 (litres per second per square kilometre), depending on the magnitude of the annual rainfall. This information could be used as a basis for well field design, where appropriate.

9.4 GROUNDWATER FLOW SYSTEMS

Groundwater flow systems are relatively slow moving and, with few exceptions, follow topographic contours. Groundwaters in the Lowveld area of eastern Swaziland show evidence of originating from the Lebombo Mountains and/or the Middleveld areas, located to the east and west respectively. Most of the recharge in Swaziland occurs in these two areas. These groundwater flow systems include a shallow, relatively young (5 to 10 years old) system which is recharged by partially evaporated surface water from the drainage network. Deeper groundwaters, with a subsurface residence time of at least forty years, are recharged by direct infiltration at higher elevations. Mixing of groundwater from shallow and deep flow systems types occurs in many boreholes.

There are numerous springs and seeps, located primarily in the Highveld and Lebombo areas. The cumulative groundwater recharge and modest storage capabilities of the shallow local strata sustains modest year round flows (1 to 5 L/s) in most of the small streams draining these regions, even during extended dry seasons. Back analysis of low flows for streams, representative of a particular region, have enabled development of order of magnitude estimates for groundwater recharge in the region.

9.5 GROUNDWATER QUALITY

On the whole, groundwater quality meets World Heath Organization standards, especially in the Highveld and Lebombo regions. A typical hydrogeochemical evolution of groundwater is from a calcium-magnesium-bicarbonate type water in the recharge areas towards a sodium-chloride type water in the discharge areas. In the Lowveld, where evapotranspiration rates are high and the rate of groundwater flushing is low, groundwaters tend to become relatively salty, with total dissolved solids commonly in excess of 1,500 mg/L.

There does not seem to be any direct correlation between fluoride concentration and hydrogeologic unit type, and there is no clear factor causing the relatively high concentrations of fluoride (up to 18 mg/L) in some Swaziland groundwaters. Anomalously high nitrate concentrations of up to 38 mg/L were also observed in some areas. The basalt units BA and BD often had high nitrate concentrations. However, as with fluoride, there was no simple correlation with hydrogeologic units. The most probable source for the nitrogen is a result of fixation in the soils around the leguminous trees and shrubs of the Acacia species, which are most common in the Lowveld area.

9.6 MANAGEMENT OF GROUNDWATER RESOURCES

Now that the groundwater resources of Swaziland have been assessed and the techniques for locating the higher yielding and better quality areas more advanced, it is likely that the groundwater will be more greatly utilized. Quantification of the groundwater potential also facilitates more efficient utilization of this valuable resource.

There is clearly a strong relationship between surface water flows and groundwater abstraction rates. Therefore, it is possible that surface water rights could be compromised if development of the hydrogeologic units is not properly managed. Ongoing studies of selected areas, flow systems and monitoring of groundwaters, as set out in Section 8 of this report, should be carried out.

The task of preserving groundwater quality and managing the abstraction rates will be much more effective under the proposed National Water Authority.

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PHOTOGRAPHS

Photo 1

TYPICAL INCISED VALLEY IN HIGHVELD:
Note exotic forest plantations

Photo 2

ROLLING HILLS AND FERTILE FIELDS IN MIDDLEVELD

Photo 3

VIEW ACROSS LOWVELD: Lebombo mountains in the background

Photo 4

UNDULATING TERRAIN, ON LEBOMBO MOUNTAIN RANGE:
Note the luxuriant vegetation, after the first rains

Photo 5

WEATHERED SOIL PROFILE: showing residual stone line

Photo 6

GRANITE PLUTON (G5): relatively impermeable except when fractured

Photo 7

GRANITE (G5): at Ntondozi

Photo 8

WEATHERED GRANITE (G5):
Note the friable nature of the soft rock

Photo 9

GRANOPHYRE (MG): In Siteki area

Photo 10

CHEVRON FOLDS: in Ngwane Gneiss (GW)

Photo 11

GNEISS (GL): Intruded by dolerite (DO), near Khubutsa

Photo 12

DETAIL OF A DOLERITE DYKE / GNEISS CONTACT (DO / GL)

Photo 13

DOLERITE SILL (DO) IN CARBONACEOUS SHALE (KN):

Photo 14

DOLERITE DYKE (DO): In Karoo Sandstone (KE)

Photo 15

DOLERITE SILL (DO): In Mhlatuze River bed

Photo 16

CLOSE UP OF BASALT (BA):
Note lack of weathering in this exposure

Photo 17

MASSIVE RHYOLITE (LR): in Lebombo escarpment

Photo 18

RHYOLITE FAULT BRECCIA (LR/FZ):
often good aquifers

Photo 19

MOZAAN QUARTZITES (MZ): Exposed in foreground and is visible in background

Photo 20

DWYKA CONGLOMERATES (KD)

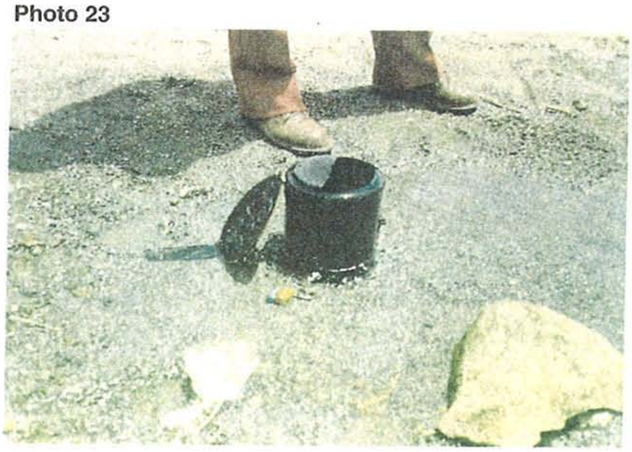
Photo 22

ALLUVIAL DEPOSITS (AL): 10km north-west of Cana

Photo 21

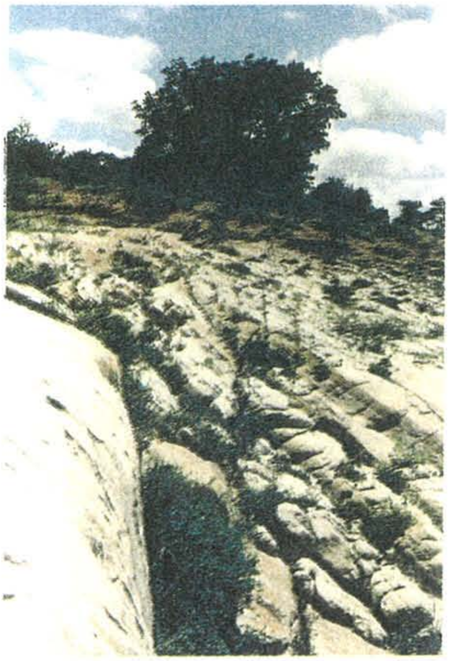
ECCA SANDSTONE (KE): Note bands of secondary mineralization

Photo 23



FLOWING BOREHOLE (AR3501): Intersected a fracture in Unit GD

Photo 24



SANDSTONE (KE):
Karoo sandstone, generally of low permeability

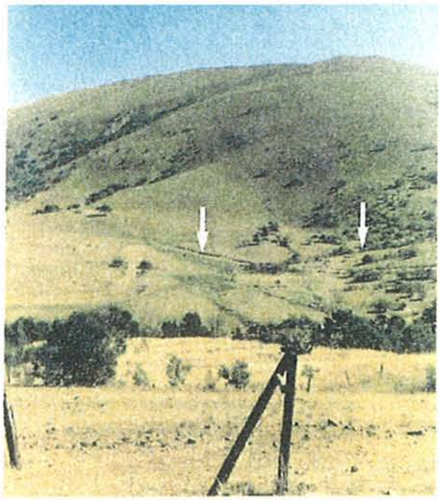
Photo 25

GNEISS CONTACT (GN / GW) SPRING (SAS121); South-east of Mankayane

Photo 26

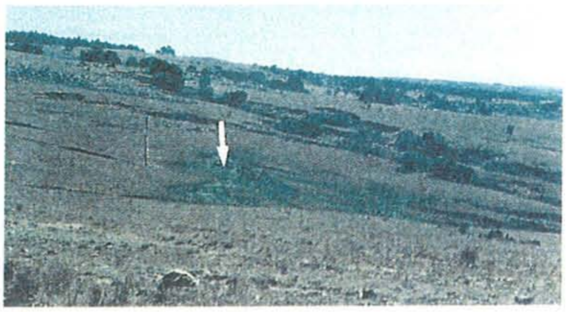
SPRING ISSUING FROM DOLERITE-GNEISS CONTACT (GL / DO):

Photo 27



SPRING AT GRANOPHYRE / LAVA CONTACT (MG / IZ):
Near Mahlangatsha

Photo 28



DEPRESSION SPRING IN GNEISS (GL): Note dongas in background

Photo 29

SPRING ISSUING FROM QUARTZITE (MZ)

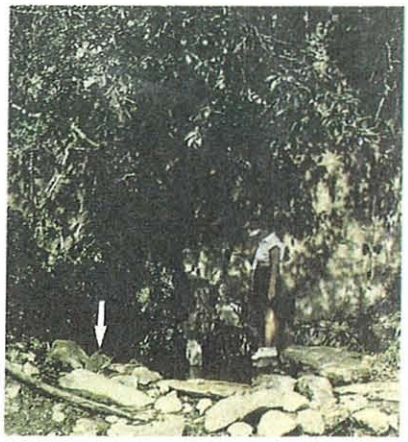
Photo 30

FAULT CONTROLLED SPRING (SAS021): in Ngwane Gneiss (GW)

Photo 31

FAIRVIEW THERMAL SPRING (S_T351): Note the silcrete deposits
Water temperature is 38°C

Photo 32



MKOBA THERMAL SPRING (S_P213):
issues from a fissure in granite (G3).

Photo 33

OVERFLOW FROM A DEVELOPED SPRING:

TABLES

TABLE : I a SUMMARY OF RAINFALL DATA FOR SELECTED[1] SWAZILAND CLIMATE STATIONS

STATION	ELEV[2] (m-asl)	MONTHLY AVERAGE (mm) JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL AVG (mm)
BIG BEND	155.0	93	68	59	37	22	14	11	9	30	49	80	85	557.0
BULEMBU	1,167.0	294.7	263.7	192.8	103.7	44.2	25.4	27.5	37.2	79.8	153.4	212.2	254.7	1,689.3
FOYER'S	381.0	121.5	111.8	85.6	57.7	30.9	15.8	12.3	13.6	39.8	80.9	113.4	128.8	812.1
LAVUMISA	135.0	83.90	80.10	54.10	41.30	23.30	13.10	10.90	14.90	31.00	55.00	81.30	88.40	577.1
MANANGA (VUVULANE)	300.0	138.7	131.4	92.8	63.9	29.4	15.3	15.4	13.8	38.5	70.9	104.3	124.6	839.0
MANKAYANE	1,009.0	147.4	123.0	105.7	53.8	24.6	12.5	15.0	13.3	42.8	88.0	129.5	130.6	886.2
MATSAPHA (MANZINI)	610.0	163.6	135.1	106.7	58.1	25.7	14.4	13.8	18.7	42.9	80.5	120.7	136.2	916.5
MBABANE	1,145.0	252.1	212.2	171.3	79.1	34.2	18.4	21.6	29.3	63.7	126.6	179.0	212.9	1,400.4
NHLANGANO	1,036.0	125.1	124.9	87.4	63.0	25.2	14.3	13.0	15.7	45.0	82.0	125.4	127.8	848.9
SIPHOFANENI	365.0	106.0	96.4	78.2	59.3	22.7	16.0	14.9	15.8	27.9	54.0	78.4	94.5	664.1
SITEKI	653.0	136.8	129.3	108.8	56.8	28.5	16.6	15.9	20.2	40.7	74.3	98.5	119.9	846.3
Minimum	135.0	83.9	68.0	54.1	37.0	22.0	12.5	10.9	9.0	27.9	49.0	78.4	85.0	557.0
Average	632.4	151.2	134.2	103.9	61.2	28.2	16.0	15.6	18.3	43.8	83.1	120.2	136.7	912.4
Maximum	1,167.0	294.7	263.7	192.8	103.7	44.2	25.4	27.5	37.2	79.8	153.4	212.2	254.7	1,689.3

NOTES: 1. For more detailed information regarding individual stations see station summaries in Appendix C
2. Elevation of substitute rainfall station presented (as named in brackets) where appropriate.

TABLE : I b SUMMARY OF TEMPERATURE DATA FOR SELECTED[1] SWAZILAND CLIMATE STATIONS

STATION	ELEV[2] (m-asl)	MONTHLY AVERAGE (°C) JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL AVG (°c)
BIG BEND	155.0	27.6	25.9	25.6	22.9	18.5	16.5	16.3	19.3	22.5	24.6	25.0	26.7	22.6
BULEMBU	1,167.0	20.0	19.9	19.2	17.7	15.3	12.9	13.2	14.7	16.5	17.4	18.5	19.6	17.0
LAVUMISA	135.0	26.5	24.2	24.1	21.8	19.9	17.6	16.8	18.6	20.2	21.0	23.0	23.4	21.4
MANANGA	230.0	25.9	25.3	24.3	22.2	19.6	16.9	17.5	19.4	21.5	22.0	23.6	25.3	21.9
MATSAPHA	642.0	23.6	23.1	22.5	20.2	18.0	15.3	15.8	16.9	19.2	20.0	21.2	22.8	19.9
MBABANE	1,145.0	20.0	19.8	18.8	17.1	14.5	12.1	12.4	14.2	16.2	17.6	18.5	19.6	16.7
NHLANGANO	1,036.0	20.8	20.9	20.2	19.5	15.6	13.5	14.5	15.6	17.1	18.2	18.9	20.3	17.9
SITEKI	653.0	22.6	22.2	22.4	20.0	18.1	15.9	15.7	17.3	18.2	19.6	20.4	22.1	19.5
Minimum	135.0	20.0	19.8	18.8	17.1	14.5	12.1	12.4	14.2	16.2	17.4	18.5	19.6	16.7
Average	645.4	23.4	22.6	22.1	20.2	17.4	15.0	15.3	17.0	18.9	20.0	21.1	22.4	19.6
Maximum	1,167.0	27.6	25.9	25.6	22.9	19.9	17.6	17.5	19.4	22.5	24.6	25.0	26.7	22.6

NOTES: 1. For more detailed information regarding individual stations see station summaries in Appendix C

TABLE II: STRATIGRAPHY OF SWAZILAND BEDROCK

ERA	SUPER-GROUP	AGE (million years)	GROUP	LITHOLOGY	DESCRIPTION OF ROCK FORMATION	HYDRO-GEOLOGIC UNIT
TERTIARY and RECENT				Alluvial SEDIMENTS	Sands, gravels and ferricretes.	AL
			Unconformity			
PALAEOZOIC (PERMIAN-JURASSIC)	POST KARROO INTRUSIVES	190		DYKE swarms and thick sills	Gabbro and dolerite	GA & DO
				GRANOPHYRES	Granophyric textured intrusion, microgranites	MG
	KARROO	200	Lebombo	Acidic ignimbrite LAVAS	Rhyolitic tuffs (with quartz phenocrysts), welded tuffs and agglomerates (about 5Km thick)	LR
			Sabie River	Mantle derived flood LAVAS	Basalt lavas with minor tuffs and intercalated rhyolites (about 5 km thick).	BA
				Basalt LAVAS	Basalt lavas: with dolerite dyke swarms	BD
			Nkondolo	Continental SEDIMENTS sedimentation (braided trains and aeolian)	Mature sandstones, pebbly sandstones, claystone (150m thick). Correlates with Cave Sandstone, Red Beds and Molteno quartzites in RSA.	KN
			Ecca – Upper	Fluviodeltaic SEDIMENTS	Claystones, coals, sandstones (160m thick).	KE
			– Middle	Fluviodeltaic SEDIMENTS	Sandstones, coals, claystones (550m thick)	KE
			– Lower	Prodeltaic SEDIMENTS	Claystones (40m thick).	KE
		300	Dwyka	GLACIAL SEDIMENTS (till (30m thick) and outwash)	Tillite, conglomerates and claystone.	KD
			Unconformity			
PROTEROZOIC-PALAEOZOIC	POST-ARCHEAN and PRE-KARROO INTRUSIVES	300–2,500?		DYKES: In Archean rocks	Dolerite, gabbro and metagabbro	DO,GA
				GRANOPHYRES	Granophyritic textured intrusive	MG
	POST PONGOLA	2,550	Mswati	GRANITE; Plutons	Coarse grained with metacrysts; mostly mica, with some hornblende (AG5 of Hunter 1961)	G5
		2,650	Hlatikulu	GRANITE; Batholith	Coarse to medium grained; relicts and xenoliths common.	GR
			Nhlangano	GNEISSES; Mantled Domes	Granite / gneiss; mantled by Pongola rocks	GL
		2,813	Usushwana	Layered basic intrusions	Microgranites, gabbro, phorphyritic granites and pyroxenite.	UC
		2,870	Mliba	GRANODIORITE; Pluton	Coarse grained intrusives; with no pegmatites	GM
	PONGOLA	2,910	Mozaan	Continental shelf SEDIMENTS (1 – 3 km thick)	Quartzite, ironstone, shales, schists, conglomerate and basalt. Upper units are metamorphosed (Mkhondo Valley).	MZ
			Insuzi	Continental LAVAS (1 km thick)	Andesitic and felsitic lavas, phyllites and quartzites	IZ
ARCHEAN			Unconformity			
	PRE-PONGOLA INTRUSIVES	3,038	Lochiel	GRANITE; Batholith	Coarse to fine grained granite, with associated dykes and sheets (AG3 of Hunter 1961)	G3
			Unconformity			
	POST SWAZILAND GNEISS COMPLEX	3,323	Mhlatuzane Tsawela and Mahamba	Metamorphics; diapirs and GNEISS rocks.	Grey biotite and hornblende gneiss, amphibolites and various metamorphics.	GN
		3,350	Usutu Suite	Massive suites of INTRUSIVES	Granodiorites, and related rocks.	GD
			Unconformity			
	SWAZILAND		Moodies	Series of Molasse SEDIMENTS	Quartzite, conglomerate.	GB
			Minor Unconformity			
			Fig Tree	Flysch SEDIMENTS	Shales, Cherts, jaspers and ironstone	GB
		3,540	Onverwacht	Ocean floor EXTRUSIONS	Acid basic volcanics.	GB
		3,540	Dwalile Metamorphic Suite	Metamorphosed VOLCANICS and SEDIMENTS	Amphibolites (hornblende), basalts, serpentinite, schists etc	DW
	PRE-SWAZILAND INTRUSIVES	3,555	Ngwane	GNEISS; Proto-continental	Tonalitic gneiss; finely layered	GW

Notes: 1) Data was developed from Wilson (1982) and Hunter (1961). Hunter's spelling of "Karroo" and "Archean" was adopted in favour of Wilson's.
2) See hydrogeologic map for information on hydrogeologic units.

TABLE III : STATISTICAL INFORMATION ON GROUPS OF HYDROGEOLOGIC UNITS

HYDROGEOLOGIC UNIT	NUMBER	BLOWN YIELDS (L/s) FOR ALL BOREHOLES						PROJECT BH's ONLY		BOREHOLE DEPTH (m) - ALL BOREHOLES					ELECTRICAL CONDUCTIVITY (µS/cm)			
	RECORDS	DATA	MIN	AVG	MAX	BOREHOLE	TOTAL	P-MAX	BOREHOLE	DATA	MIN	AVG	MAX	TOTAL	DATA	MIN	AVG	MAX
GRANITICS:																		
Granites (G3, G5 ,GR)	302	141	0.01	1.15	8.0	_K28-02	163.1	6.6	_K28-02	149	10.0	61.2	106.8	9117.1	79	10	264	920
Granodiorites (GD, GM)	199	106	0.01	1.59	20.0	AE24-01	169.0	20.0	AE24-01	112	11.0	49.4	122.0	5,528.8	68	50	734	4,000
METAMORPHICS:																		
Gneiss (GL, GN, GW)	395	204	0.01	1.53	12.0	AA34-31	312.3	6.7	AI29-01	225	6.0	56.5	137.2	12,713.0	166	26	250	2,280
Intrusives (DO, DW, GA)	54	38	0.01	1.06	6.6	AR00-01	40.3	6.6	AR00-01	44	3.0	52.9	112.4	2,326.2	17	27	376	2,880
VOLCANICS:																		
Basalts (BA, BA/WE, BD)	209	162	0.01	1.00	6.8	BC46-62	161.8	6.7	BA45-01	186	7.0	67.8	305.2	12,616.5	65	275	1,544	3,000
Rhyolotes (LR)	99	33	0.01	0.66	4.5	AV49-81	24.8	2.0	AG45-01	40	16.8	71.6	122.8	2,864.0	31	120	645	2,150
Other Volcanics (UC, IZ, GB)	53	29	0.01	0.88	8.0	_X08-01	52.2	8.0	_X08-01	28	27.6	58.7	122.1	1,643.9	16	40	228	900
SEDIMENTARY:																		
Mozaan (MZ)	25	16	0.01	2.29	6.7	BC27-01	36.7	6.7	BC27-01	17	50.0	68.8	91.5	1,170.0	8	65	110	210
Karroo (KD, KE, KN)	159	115	0.01	2.50	8.4	AF41-31	101.0	4.0	BE09-01	139	3.0	63.1	195.2	8,774.3	27	180	1,279	4,000
OTHER																		
Alluvium	10	7	0.36	1.90	5.0	_O31-01	13.3	5.0	_O31-01	7	24.4	38.6	26.3	270.3	3	550	662	725
Shear zones (MY, SC, AM)	57	25	0.01	1.16	8.0	AM32-06	29.0	8.0	AM32-06	38	7.7	65.8	146.4	2,501.2	23	40	357	1,100
Fault zones (FZ)	91	70	0.01	2.65	20.0	AE24-01	185.6	20.0	AE24-01	63	5.2	68.9	164.8	4,338.6	51	35	717	2,350
SUMMARY (Sum, Min, Avg, Max etc) :	1,653	946	0.01	1.36	20.0		1,288.9	20.0		1,048	3.0	60.9	305.2	63,863.9	554	10	660	4,000

NOTES:

1) Data, except P-max, is based on all available data.

2) P-max is based on Project data only.

TABLE IV : SUMMARY OF INFORMATION ON HYDROGEOLOGIC UNIT

HYDROGEOLOGIC UNIT		NUMBER	BLOWN YIELDS (L/s) FOR ALL BOREHOLES						PROJECT BH's ONLY		BOREHOLE DEPTH (m) - ALL BOREHOLES					ELECTRICAL CONDUCTIVITY (μS/cm)			
		RECORDS	DATA	MIN	AVG	MAX	BOREHOLE	TOTAL	P-MAX	BOREHOLE	DATA	MIN	AVG	MAX	TOTAL	DATA	MIN	AVG	MAX
AL	Alluvium	10	7	0.36	1.90	5.0	_O31-01	13.28	5.0	_O31-01	7	24.4	22.3	26.3	270.3	3	550	662	725
AM	Amphibolite	9	3	1.00	2.97	5.0	BA28-01	8.90	5.0	BA28-01	3	41.3	59.8	83.3	179.5	4	40	254	634
BA	Basalt: no dykes or weathering	80	51	0.01	0.76	0.83	BL46-01	38.78	0.83	BL46-01	76	7.0	66.91	180.0	5,084.8	31	275	1,450	3,000
BA/WE	Weathered Basalt	25	25	0.01	2.44	6.7	BA45-01	61.01	6.7	BA45-01	21	31.4	65.1	103.7	1,367.1	9	900	1,928	3,000
BD	Dyke Swarm Basalt	104	86	0.01	0.72	6.8	BR41-51	62.02	3.3	_W44-01	89	10.0	69.3	305.2	6,164.6	25	700	1,255	2,050
DO	Dolerite or Diabase	46	35	0.01	0.95	5.0	AP39-02	33.24	5.0	AP39-02	36	11.4	61.1	112.4	2,200.8	15	27	1,129	2,880
DW	Dwallie Metamorphic Suite	1	1			6.6	AR00-01	6.60	6.6	AR00-01	1					1			
FZ	Fault Zone	91	70	0.01	2.65	20.0	AE24-01	185.55	20.0	AE24-01	63	5.2	68.9	164.8	4,338.6	51	35	717	2,350
G3	Lochiel Granite (AG3)	157	80	0.01	1.17	7.0	_K28-02	93.63	6.6	_K28-02	83	10	59.3	137.3	4,949.6	35	20	389	1,803
G5	Mswati Granite (AG5)	94	31	0.01	0.86	5.0	AM31-03	26.78	2.9	AM31-03	33	28.3	74.3	191	2,452.2	31	25	179	1,300
GA	Gabbro	7	2	0.01		0.40	_X42-12	0.41	0.01	AC07-01	7	3.0	17.9	67.1	125.4	1	80		80
GB	Greenstone Belt Sediments and Lavas	14	12	0.01	2.58	8.0	_X08-01	31.01	8.0	_X08-01	12	27.6	75.6	103.7	910.7	8	40	244	900
GD	Granodiorite (Usutu Suite)	183	97	0.01	1.61	20.0	AE24-01	156.50	20.0	AE24-01	102	16.0	48.5	122.0	4,948.7	64	50	246	4,000
GL	Nhlangano Gneiss	44	21	0.01	1.28	8.5	BN16-01	26.85	5.0	BN16-01	18	6.0	58.4	103.7	1,051.1	24	26	118	250
GM	Mliba Granodiorite	16	9	0.01	0.60	6.7	_Z30-01	12.50	6.7	_Z30-01	10	11.0	58.0	91.5	580.1	4	410	1,221	2,470
GN	Other Gneisses	43	22	0.01	1.43	4.0	AE15-02	31.37	4.0	AE15-02	24	24.4	46.9	110.0	1,366.6	15	100	344	2,280
GR	Other Granites	51	30	0.01	1.42	5.0	BK25-51	42.69	1.3	BO26-01	33	14.6	52.0	106.8	1,715.3	13	10	224	920
GW	Ngwane Gneiss	308	161	0.01	1.58	12.0	AA34-31	254.05	6.7	AI29-01	183	12.2	56.3	137.2	10,295.3	127	33	288	1,600
IZ	Insuzi Group	28	15	0.01	1.08	6.6	AX14-01	16.19	6.6	AX14-01	14	33.0	66.0	122.1	623.5	6	91	337	725
KD	Dwyka Group of Karoo Sediments	4	4	0.01	0.93	2.0	BH24-01	3.72	2.0	BH24-01	4	36.6	69.9	97.6	279.5	3	190	463	1,000
KE	Ecca Group of Karoo Sediments	107	76	0.01	0.57	4.8	BJ11-51	43.02	4.0	BE09-01	93	3.0	67.8	195.2	6,305.5	15	180	1,751	4,000
KN	Nkondola Group of Karoo Sediments	48	35	0.01	1.55	8.4	AF41-31	54.28	2.0	AF41-03	42	10.0	52.1	171.8	2,189.3	9	565	1,623	3,500
LR	Lebombo Rhyolites	99	33	0.01	0.66	4.5	AV49-81	24.83	2.0	AG45-01	40	16.8	71.6	122.8	2,864.0	31	120	645	2,150
MY	Mylonite	40	20	0.01	0.88	8.0	AM32-06	17.58	8.0	AM32-06	30	16.0	68.8	146.4	2,064.0	17	200	726	1,100
MZ	Mozaan Group	25	16	0.01	2.29	6.7	BC27-01	36.65	6.7	BC27-01	17	50.0	68.8	91.5	1,170.0	8	65	110	210
SC	Schist	8	2	1.20	1.25	1.3	_Y09-81	2.50			5	7.7	51.5	70.0	257.7	2	55	90	124
UC	Usushwana Complex	11	2	1.00	2.50	4.0	AC08-01	5.00	4.0	AC08-01	2	51.8	58.9	57.9	109.7	2	90	102	115
	TOTAL :	1,653	946					1,288.9			1,048				63,863.9	554			
	Minimum (MIN)			0.01								3.00					10.00		
	Average (AVG)				1.36								60.9					659.80	
	Maximum (MAX)					20.0			20.0					305.2					4,000

NOTES:

1) Data, except P-max, is based on all available data.

2) P-max is based on Project data only.

2) P-max is based on Project data only.

TABLE : V DISTRIBUTION OF BOREHOLE YIELDS BY UNIT TYPE

UNIT TYPE		BLOWN YIELD (L/s)																		TOTAL BOREHOLES			
MAJOR	From		0.01	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5	7.0	7.5	>8.0	WITH	NO	ALL	%
	To	0.01	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5	7.0	7.5	8.0	20	YIELDS	DATA		ALL
BA		8	22	12	8	4	1	1				1				4				61	16	77	5.66
BA*		10	27	18	9	11	3	1	3			1				5				88	17	105	7.72
BA/WE		1	4	3	1	7	2		2							1				21		21	1.54
BD		14	38	15	5	1	4	2	1	2						1				83	17	100	7.35
BD*		14	39	17	5	1	4	2	1	2						1				86	17	103	7.57
DO		10	7	3	1	1	2					1								25	6	31	2.28
DO*		11	9	5	2	2	3	1		1		1								35	7	42	3.09
FZ*		6	11	16	6	9	2	1	2	2		4				6			5	70	11	81	5.96
G3		11	25	4	6	3	4	1		2		3				1				60	19	79	5.81
G3/DO		5	5	1				1		1						1				14	14	28	2.06
G3*		16	30	8	6	3	5	2		3		5				2				80	21	101	7.43
G5		3	6	6	2		2	1				1								21	10	31	2.28
G5*		7	10	6	2	2	2	1				1								31	10	41	3.01
GD		7	8	4	5		3	5		1		1								34	23	57	4.19
GD*		9	23	18	12	12	6	8		3	1	2				2			1	97	66	163	11.9
GD/WE			14	13	6	9	3	1		1	1	1				1			1	51	41	92	6.76
GL		8	2		2		1	2				1							1	17	15	32	2.35
GL*		8	2	1	2	1	2	2		1		1							1	21	15	36	2.64
GN		5	4	3		2	3	2		2										21	5	26	1.91
GN*		6	4	3		2	3	2		3										23	7	30	2.20
GR		3	9	1	9		1	1		1		1								26	6	32	2.35
GR*		3	10	2	9		1	1		1		2								29	7	36	2.64
GW		9	32	12	7	6	8	3	1	4		3					1		2	88	63	151	11.1
GW*		12	49	34	11	12	11	11	2	9		6			1	1	1		3	163	107	270	19.8
GW/WE		1	12	15	1	4		7	1	2		2			1					46	40	86	6.32
KE		11	18	7	2	2	1			1										42	24	66	4.85
KE*		20	34	11	3	4	1			3		1								77	28	105	7.72
KE/DO		7	13	2	1	2				1										26	3	29	2.13
KN		2	11	6	1	2	3	1	1	2									2	31	12	43	3.16
KN*		3	13	6	1	2	5	1	1	2									2	36	13	49	3.60
LR		6	12	6			1			1	1									27	14	41	3.01
LR*		7	15	6	1	1	1			1	1									33	15	48	3.53
MY		4	5	3	1	1												1		15	11	26	1.91
MY*		5	7	4	2	1												1		20	11	31	2.28
MZ*		2	1	3	2	1		3		1		2				1				16	9	25	1.83
Undefined																						68	5.00
TOTAL:		141	285	161	75	65	49	39	9	33	·2	28			1	19	1	1	12	921	370	1359	100
% of Total		15.3	30.9	17.5	8.1	7.1	5.3	4.2	1.0	3.6	0.22	3.0			0.11	2.1	0.11	0.11	1.3	100	28.659		
Cum % Total		15.3	46.3	63.7	71.9	78.9	84.3	88.5	89.5	93.1	93.3	96.3	96.3	96.3	96.4	98.5	98.6	98.7	100				

NOTE: * Signifies that all boreholes with this hydrogeologic unit specified, whether a major or minor unit (i.e."All Types") are included in the population

TABLE : VI SUMMARY OF DATA ON SELECTED DISCHARGE ZONES

HYDROGEOLOGICAL UNIT	NO. OF SPRINGS	DISCHARGE (L/s)			WATER							SPRING WITH MAXIMUM FLOW RATE			
					CHEM. DATA.	E.C. (μS/cm)			TEMP (°C)						
		Min	Max	Avg		Min	Max	Avg	Min	Max	Avg	Spring Name	Flow (L/s)	Elev (m)	Map
AL	2	1.5	1.5	1.5	0	NA	NA	NA	NA	NA	NA	S_B251	1.5	412	2
AM	4	0.5	4.6	0.8	0	130	200	157	24	24	24	SBM131	4.6	NA	28
BA	2	0.8	0.8	0.8	1	275	275	275	23	23	23	SAG441	0.8	612	14
BD	1	NA	NA	NA	1	788	788	788	NA	NA	NA	SAI441	NA	343	14
DO	4	1.0	9.3	5.2	2	27	400	214	NA	NA	NA	SBO151	9.3	NA	28
FZ	10	0.6	7.4	2.8	2	28	390	236	19	21	20	S_J201	7.4	680	2
GB	6	0.2	5.6	2.4	1	75	75	75	NA	NA	NA	S_E211	5.6	555	2
GD	21	0.3	9.6	3.0	8	38	640	310	22	44	37	SAN181	9.6	181	19
GM	1	3.0	3.0	3.0	1			410			38	S_T351	3.0	296	7
GN	14	0.3	55.6	6.8	6	5	200	148	20	33	26	SBA281	56.6	NA	24
GW	41	0.2	48.0	5.6	12	33	516	165	22	45	30	SAR131	63.7	NA	17
GR	14	0.3	22.7	5.0	1	40	400	132	NA	NA	NA	SBJ271	42.5	NA	29
G3	55	0.1	9.6	1.4	5	20	200	56	16	52	32	SAI051	9.6	1260	10
G5	54	0.1	49.6	4.0	16	21	210	63	14	52	24	SBM232	49.6	850	29
IZ	12	0.1	4.8	1.2	0	45	80	62	23	23	23	SAZ082	4.8	NA	22
KE	5	0.1	4.1	2.6	0	100	150	125	NA	NA	NA	SB0152	4.1	NA	28
LA	1	2.3	2.3	2.3	0	NA	NA	NA	NA	NA	NA	S_G201	2.3	630	2
MG	2	0.4	0.4	0.4	0	110	110	110	NA	NA	NA	SAX091	0.4	NA	23
MY	9	0.1	1.1	0.5	2	200	247	224	26	26	26	SAN332	1.1	309	19
MZ	6	0.3	3.9	2.0	2	40	210	121	17	17	17	SBG241	3.9	745	29
SC	1	NA	NA	NA	0	NA	NA	NA	NA	NA	NA	S_Y091	NA	NA	11
SH	1	0.8	0.8	0.8	0	NA	NA	NA	NA	NA	NA	S_D221	0.8	500	2
SS	1	0.7	0.7	0.7	1	200	200	200	NA	NA	NA	S_M471	0.7	559	4
UC	9	0.5	1.3	0.9	0	20	20	20	NA	NA	NA	SAC093	1.3	NA	11
TOTAL:	276	0.1	55.6	2.4	61	5	788	195	5	52	27				

NOTES: 1) E.C. = ELECTRICAL CONDUCTIVITY

2) TEMP = TEMPERATURE

TABLE: IX CONCENTRATION OF FLUORIDE AND NITRATE; BY HYDROGEOLOGICAL UNIT

	FLUORIDE			No. of	NITRATE			No. of
Unit	Min	Avg	Max	Records	Min.	Avg	Max	Records
AM	0.40	1.78	5.0	4	0.9	5.0	17.0	4
BA	0.10	0.85	3.6	32	0.1	5.9	29.0	39
BD	0.20	0.71	2.8	18	0.1	6.1	15.0	20
DO	0.10	0.36	1.0	12	L 0.1	6.2	22.6	12
FZ	0.10	1.10	18.4	38	0.1	3.0	17.0	48
G3	0.10	0.61	2.9	26	0.1	3.1	28.0	30
G5	0.10	0.56	4.6	30	0.1	2.6	19.4	29
GB	0.10	0.13	0.3	6	0.3	0.8	1.4	5
GD	0.10	0.61	9.8	63	0.1	1.8	9.7	56
GL	0.10	0.43	2.8	21	0.3	1.9	5.8	24
GM	0.30	1.05	2.6	4				
GN	0.10	1.31	5.4	14	0.1	1.4	3.9	15
GR	0.10	0.65	2.4	11	0.3	2.2	4.4	10
GW	0.10	0.63	8.0	103	0.1	2.6	24.0	106
IZ	0.10	0.35	0.7	4	0.5	3.4	9.2	5
KE	0.10	0.84	3.8	9	0.1	1.8	6.5	12
KN	0.30	0.69	1.6	9	0.8	6.7	21.7	8
LR	0.10	1.15	5.2	18	0.1	5.9	37.5	31
MY	0.30	1.34	2.8	9	0.1	2.7	12.0	10
MZ	0.10	0.10	0.1	6	0.7	1.3	2.0	8
Statistics								
Minimum	0.10	0.10	0.1	4.0	0.00	0.8	1.4	4.0
Average	0.15	0.76	4.2	21.9	0.26	3.4	15.1	24.8
Maximum	0.40	1.78	18.4	103.0	0.90	6.7	37.5	106.0

NOTES: 1) SEE FIGURES 55 AND 56 FOR DISTRIBUTION THROUGHOUT SWAZILAND

TABLE: X ESTIMATES OF TOTAL GROUNDWATER RECHARGE AND USAGE

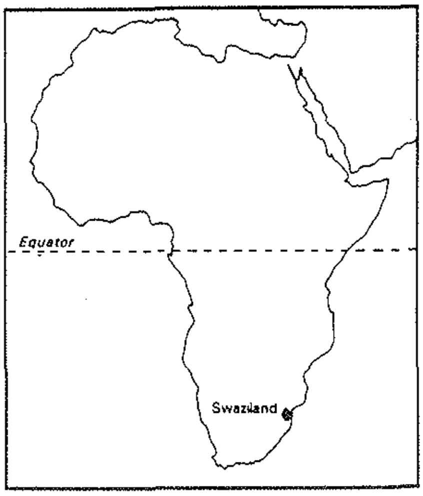
PARAMETER	REGION ---> UNITS	LOWVELD	MIDDLEVELD	HIGHVELD	LEBOMBO	TOTAL	WEIGHTED AVERAGE
AVERAGE ANNUAL RAINFALL	(mm)	620	800	1,100	820		
PERCENT RECHARGE	(%)	2	5	10	5		
EQUIVALENT RECHARGE FLUX	(L/s/Km²)	0.4	1.3	3.5	1.3		
TOTAL AREA	(Km²)	6,421	4,512	5,032	1,388	17,353	
PORTION EFFECTIVE AS RECHARGE AREA (	(%)	45	70	80	70		
EFFECTIVE AREA	(Km²)	2;889	3,158	4,026	972	11,045	
ANNUAL RECHARGE	(L/s)	1,100	4,000	14,000	1,300	20,400	
NUMBER OF EXISTING BOREHOLES		762	477	131	49	1,419	
AVERAGE BLOWN YIELD (4)	(L/s)	1.2	1.6	2.6	1.1		1.4
YIELD REDUCTION FACTOR	(L/s)	0.5	0.7	0.8	0.7		0.7
AVERAGE LONGTERM YIELD (4)	(L/s)	0.6	1.1	2.1	0.8		1.0
POTENTIAL TOTAL BOREHOLE YIELD (4)	(L/s)	473	530	274	37	1,313	
PERCENT OF POTENTIAL (3) (4)		43.0	13.2	2.0	2.9		6.4

NOTES :

1) TOTAL BLOWN YIELD OF ALL BOREHOLES (946) WITH YIELD DATA AND DRILLED BEFORE MARCH 31, 1991 IS ABOUT 1,289 L/s. i.e. AVERAGE YIELD IS 1.36 L/s.
2) EXCLUDES: CADASTRAL FEATURES, STEEP HILLSIDES, CONFINED AQUIFER ZONES AND GROUNDWATER DISCHARGE AREAS.
3) NOTE THESE FIGURES ARE VERY APPROXIMATE AND SHOULD ONLY BE USED AS A RELATIVE GUIDE TO THE CURRENT SITUATION. ACTUAL PERCENTAGES COULD BE AS MUCH AS 25% OF THESE VALUES.
4) MOST BOREHOLES ARE NOT BEING PUMPED AT RATES THEIR POTENTIAL.

FIGURES

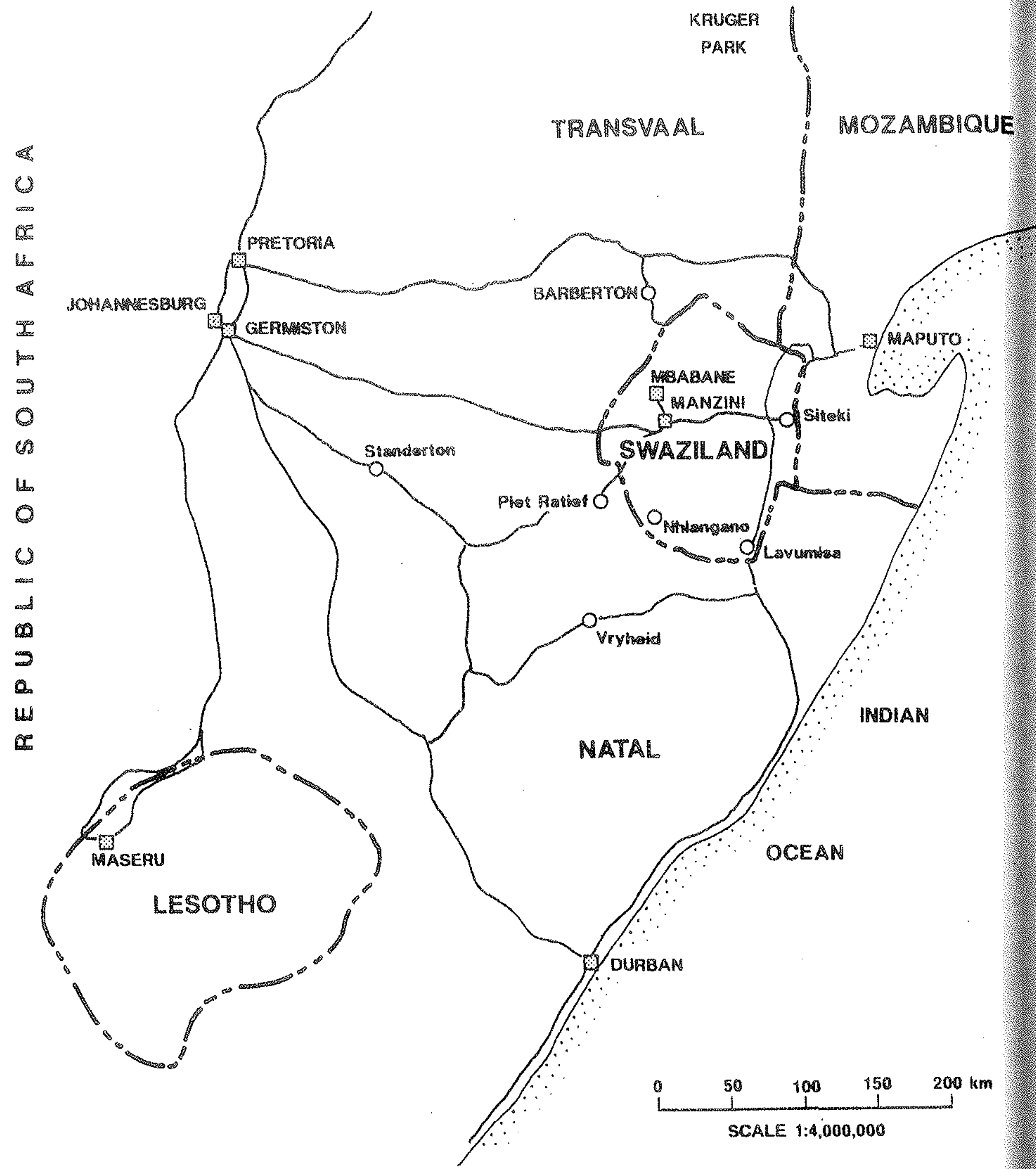
Africa



Southern Africa

Note: Adapted from Goudie and Williams 1983.

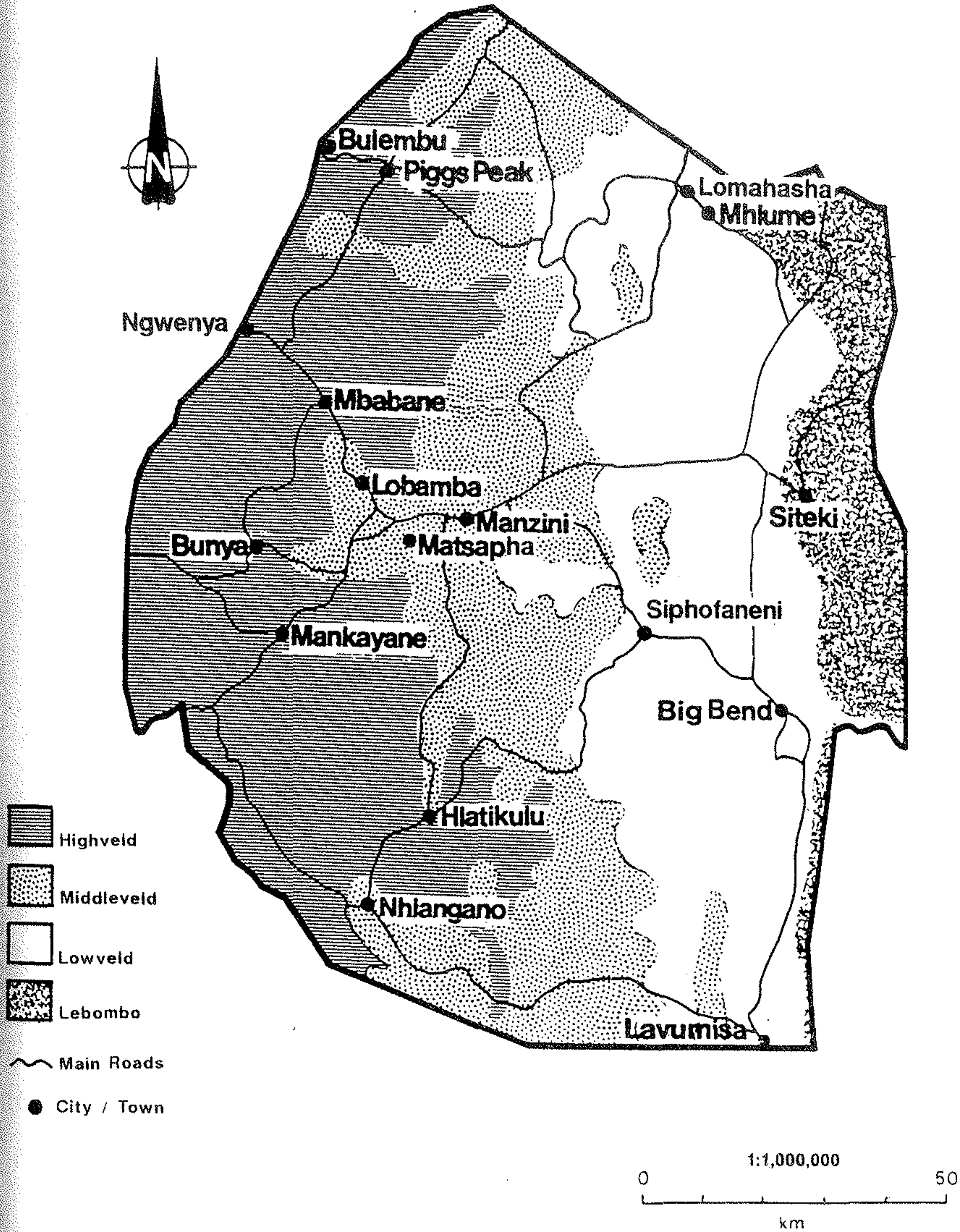
LOCATION MAP | FIGURE: 1



AREA MAP

FIGURE: 2

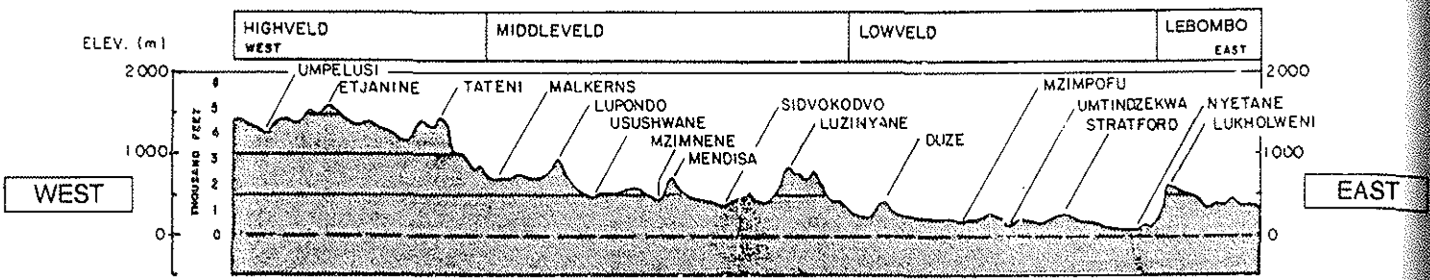
WEST			EAST
HIGHVELD	MIDDLEVELD	LOWVELD	LEBOMBO



Note: Adapted from Goudie and Williams 1983.

PHYSIOGRAPHIC REGIONS

FIGURE: 3

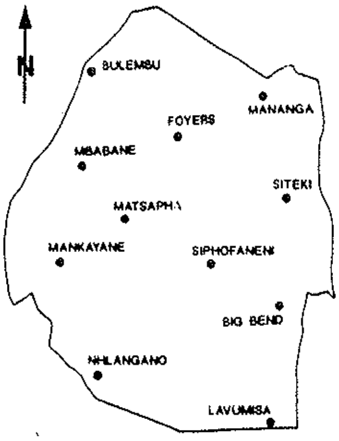


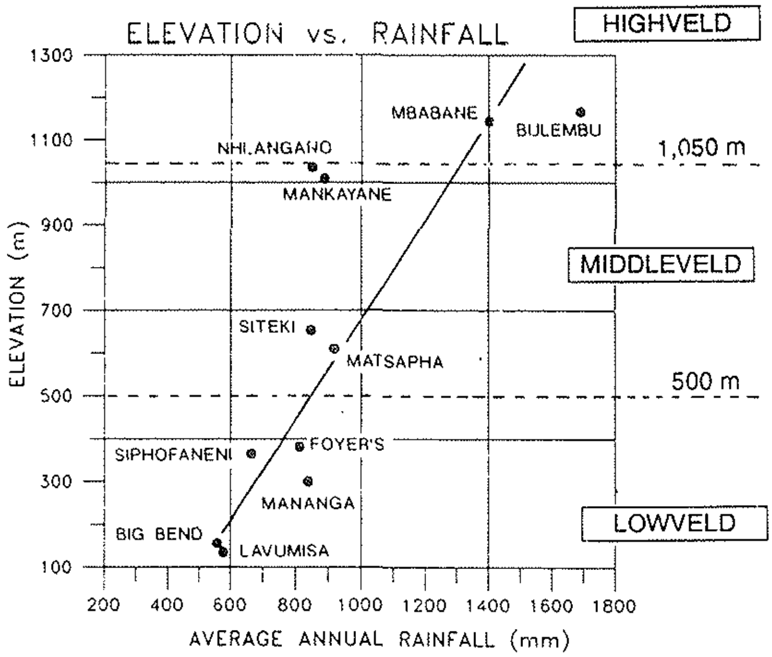
TOPOGRAPHIC SECTION ACROSS SWAZILAND

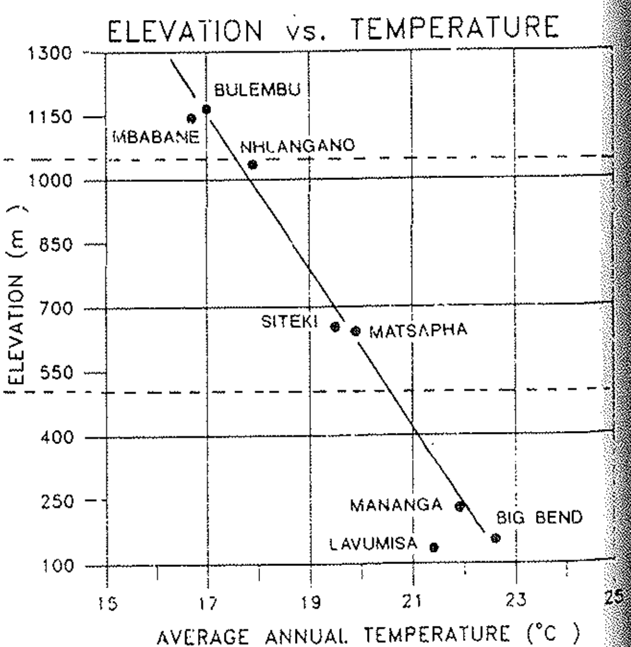
1 to 13km north of the Lusutu River, approximately west-east

Horizontal scale 1:1,000,000

Vertical scale 1:100,000

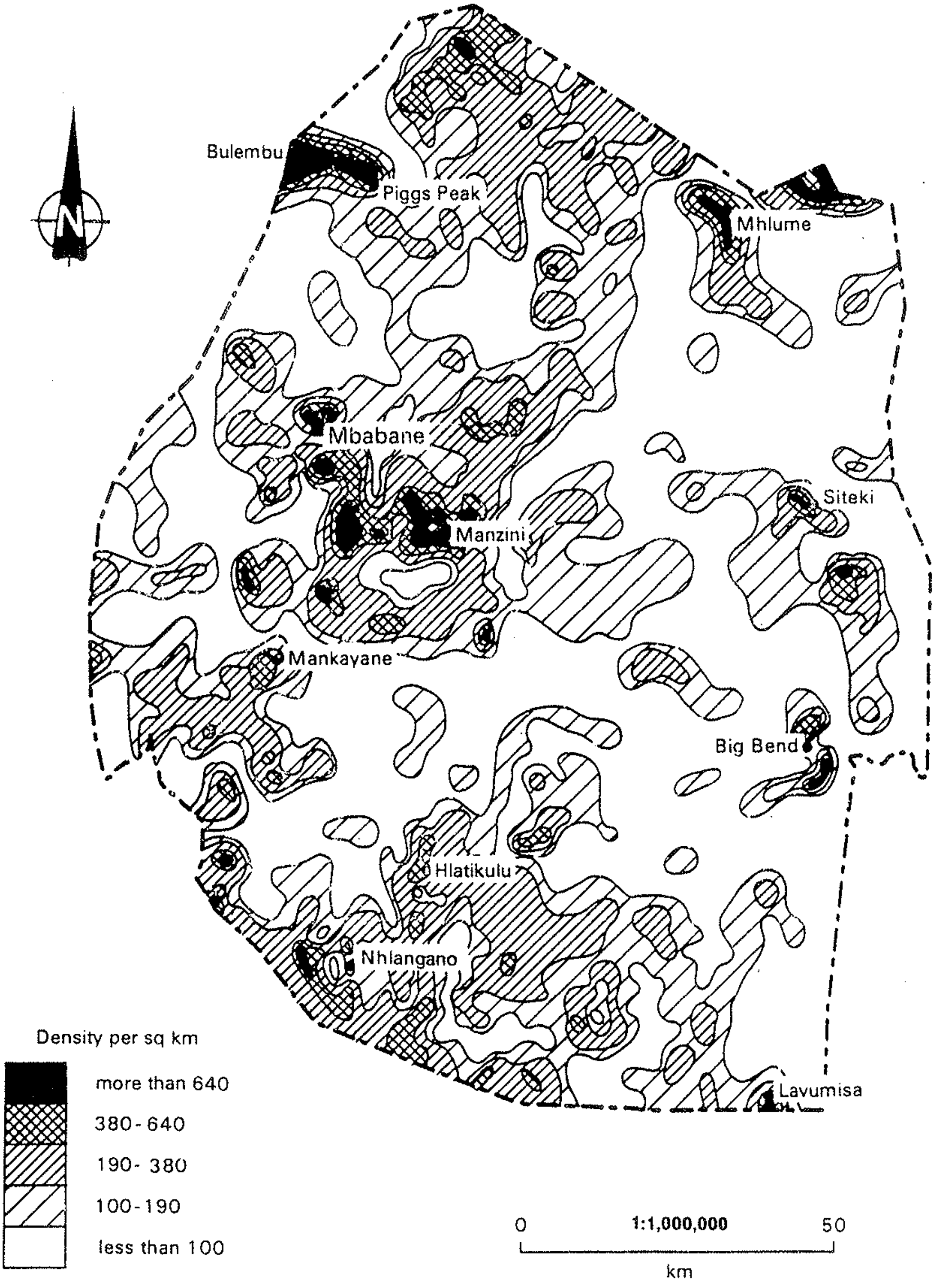






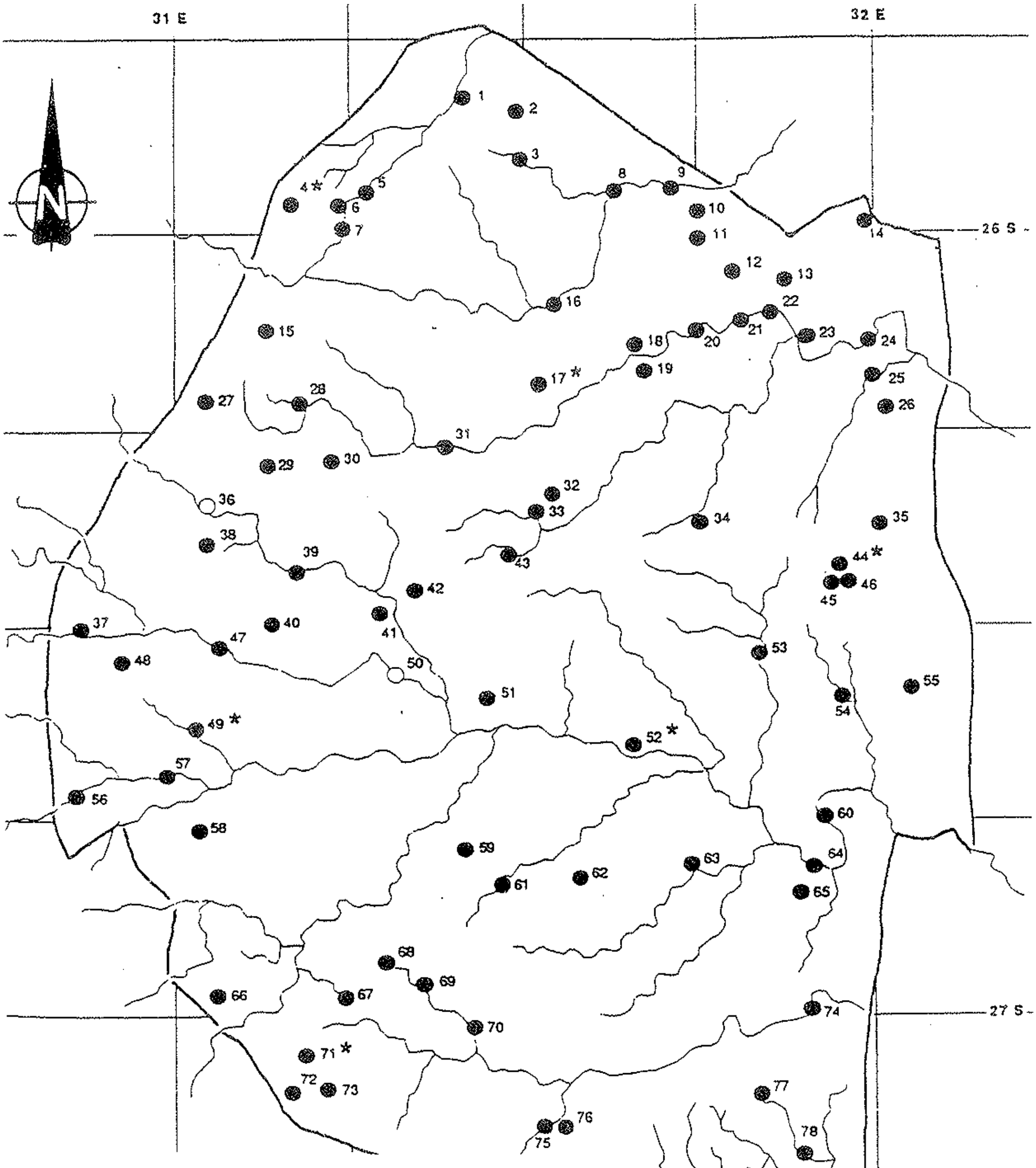
WEST TO EAST TOPOGRAPHIC PROFILE AND CLIMATE - ELEVATION RELATIONSHIPS

FIGURE: 4



Note: Adapted from Goudie and Williams 1983.

POPULATION DENSITY | **FIGURE: 6**



1 NGONONI
2 MAYIWANE RANCH '
3 MAYIWANE RDA
4 BULEMBU
5 ROCKLANDS
6 PIGGS PEAK
7 SWAZI PLANTATIONS
8 SIHHOYA
9 TUNIZINI
10 BORDERGATE
11 MANANGA
12 MHLUME
13 MANANGA AG
14 LOMAHASHA
15 MALOLOTJA
16 MADLANGAMPISI
17 FOYERS-BRADA
18 MNJOLI
19 MLIBA
20 HOMESTEAD
21 LIKIMA
22 VUVULANE
23 TARANKULA
24 NKALASHANE
25 MULAWULA
26 LUBOMBO
27 MOTJANE
28 MBULUZI
29 MBABANE
30 MAZIMBA
31 BHEKINKOSL
32 DINEDOR
33 MPISI
34 MPAKA
35 SITSATSAWENI
36 SIPHOCOSINI
37 MANGCONGCO
38 MHLAMBANYATSI
39 MLILWANE
40 MALKERNS
41 MATSAPHA
42 MANZINI
43 ST JOSEPH
44 SITEKI
45 MABUDA
46 GOOD SHEPHERD
47 USUTU PULP
48 SEMHLANGENI
49 MANKAYANE
50 GEBENI
51 SAN ROY
52 SIPHOFANENI
53 MPOLONJELI
54 NYETANE
55 TIKUBA
56 LUSHIKISHINI
57 NGWEMPISI
58 MAHLANGGATIA
59 BLOEMONDALE
60 LUBOMBO
61 KUBUTA
62 SITHOBELLA
63 ST PHILIPS
64 BIG BEND
65 MANYONYANENI
66 JOHANNESLOP
67 DWALENI
68 HLATIKULU
69 NTONGA
70 NEWHAVEN
71 NHLANGANO
72 MASEYISINI
73 DWALENI
74 NSOKO
75 HLUTI
76 HLUTI
77 MLINDAZWE
78 MHKULAMINI
79 LAVUMISA

LEGEND

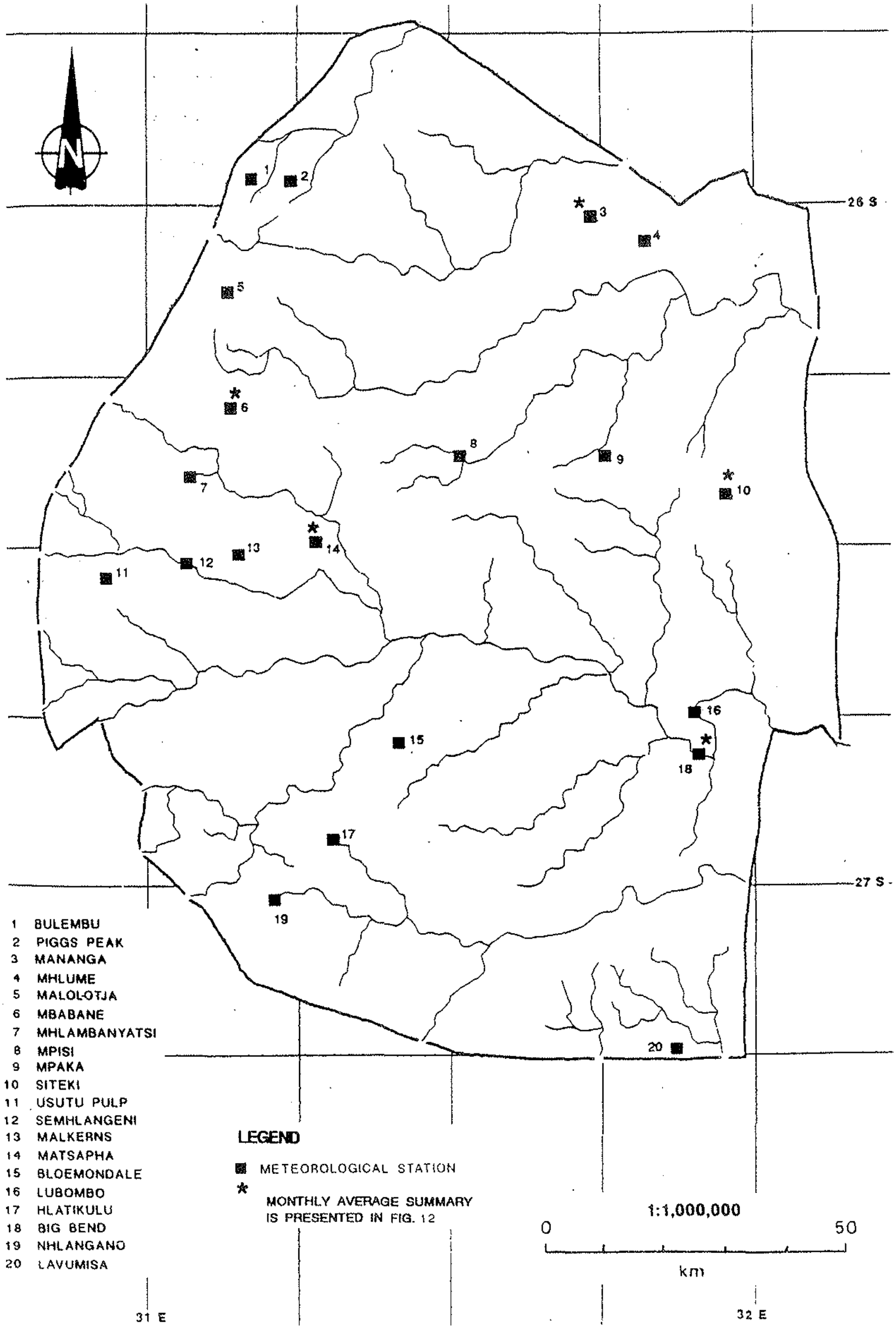
- ● RAINFALL STATION
- ○ CLOSED RAINFALL STATION
- * MONTHLY AVERAGE SUMMARY IS PRESENTED IN FIG. 11

1:1,000,000

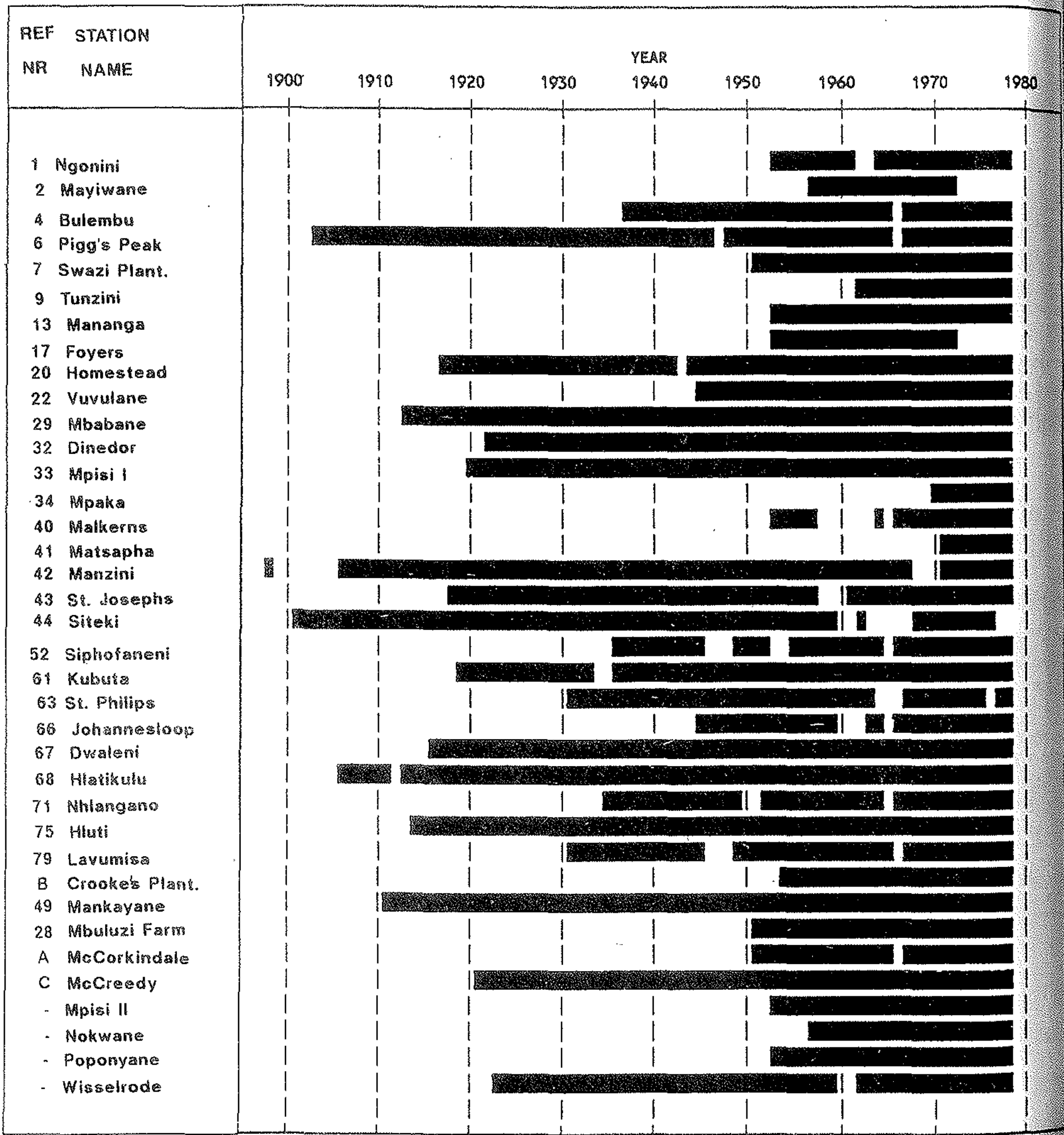
0 — 50 km

RAINFALL STATIONS

FIGURE: 7



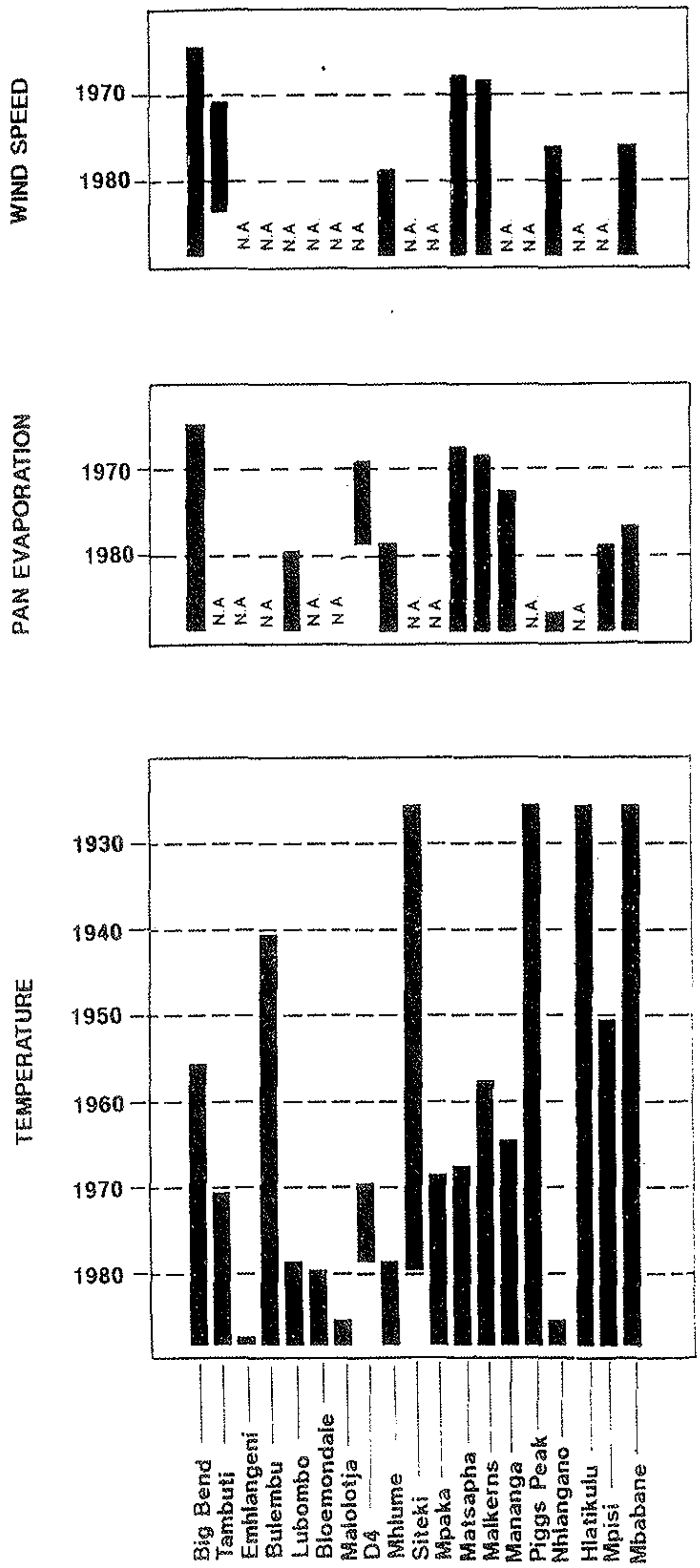
METEOROLOGICAL STATIONS | FIGURE: 8



NOTES:
1) SEE HISTOGRAMS OF DATA ON FIGS.11 AND 12. AND IN APPENDIX C.
2) ADAPTED FROM MACDONALD & PARTNERS LIMITED, JAN. 1990

LENGTH OF RAINFALL RECORDS

FIGURE: 9



N.A = NOT AVAILABLE

NOTES:

1) SEE HISTOGRAMS OF DATA ON FIGS.11 AND 12. AND IN APPENDIX C.

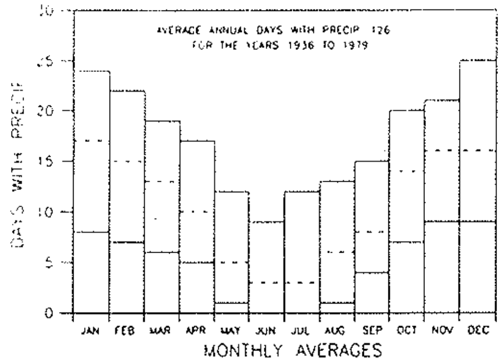
2) ADAPTED FROM MACDONALD & PARTNERS LIMITED. JAN. 1990

LENGTH OF METEOROLOGICAL RECORDS

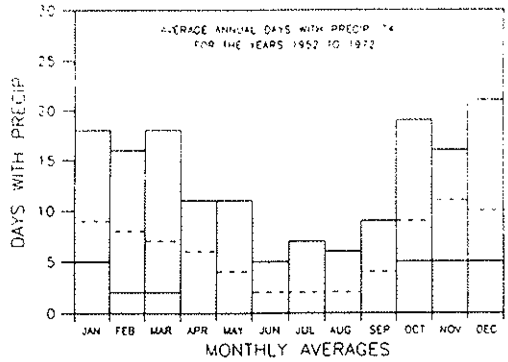
FIGURE: 10

RAIN DAYS

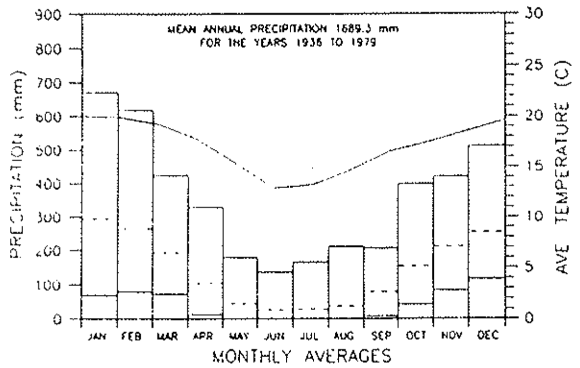
BULEMBU WEATHER STATION (4)

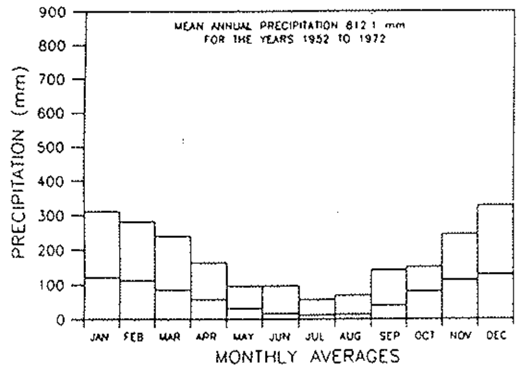


FOYERS WEATHER STATION (17)



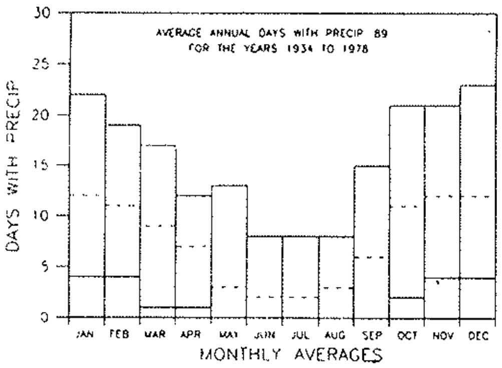
TEMPERATURE AND PRECIPITATION



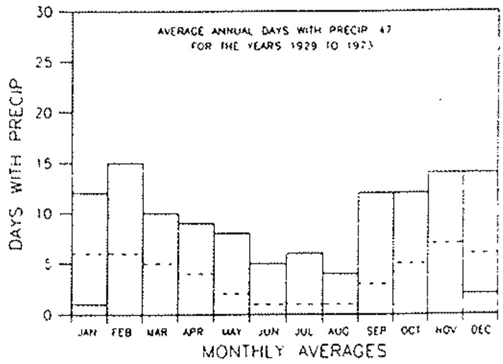


RAIN DAYS

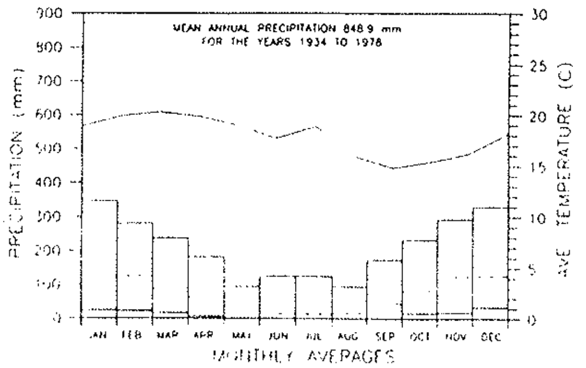
NHLANGANO WEATHER STATION (71)

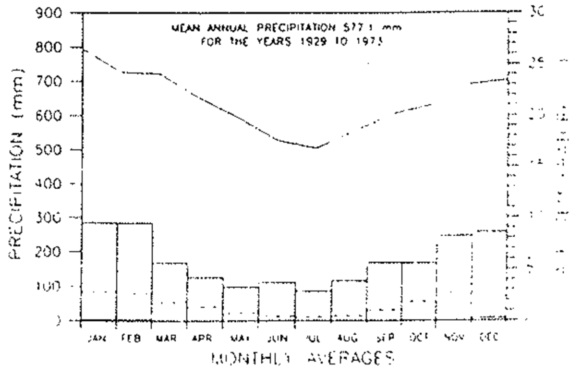


LAVUMISA WEATHER STATION (79)



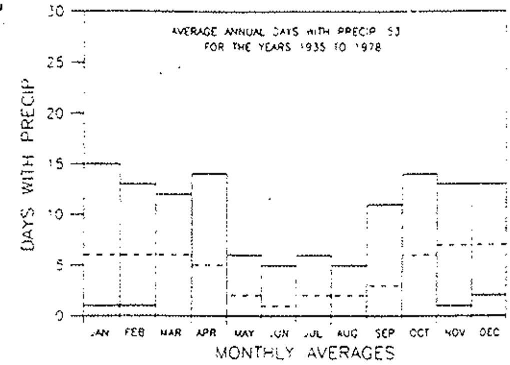
TEMPERATURE AND PRECIPITATION



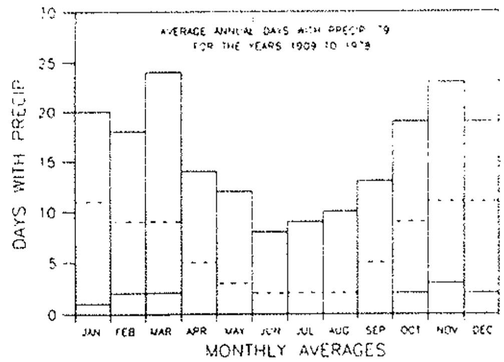


RAIN DAYS

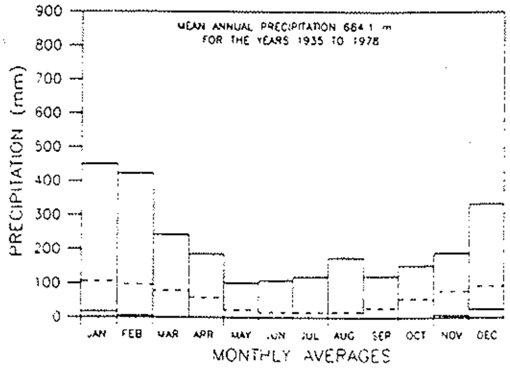
SIPHOFANENI WEATHER STATION (52)

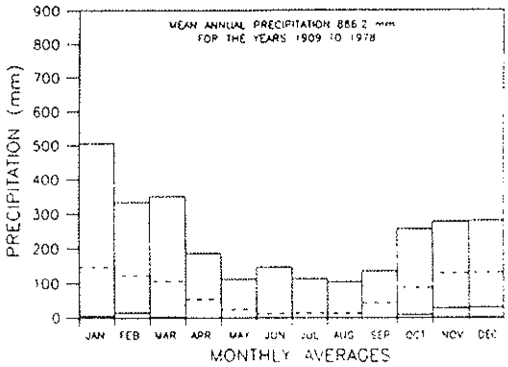


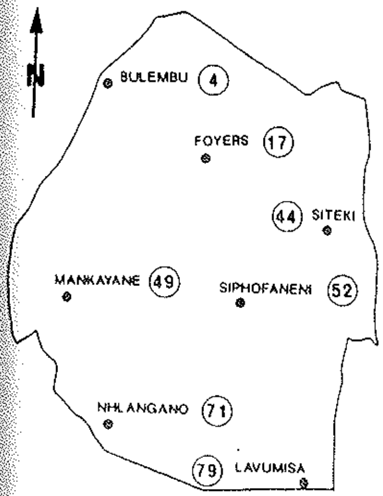
MANKAYANE WEATHER STATION (49)

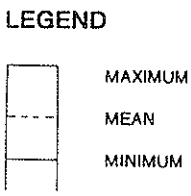


TEMPERATURE AND PRECIPITATION



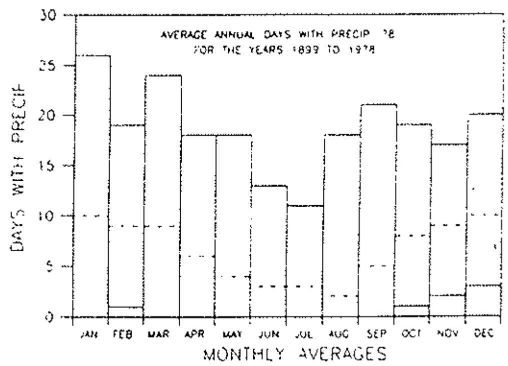




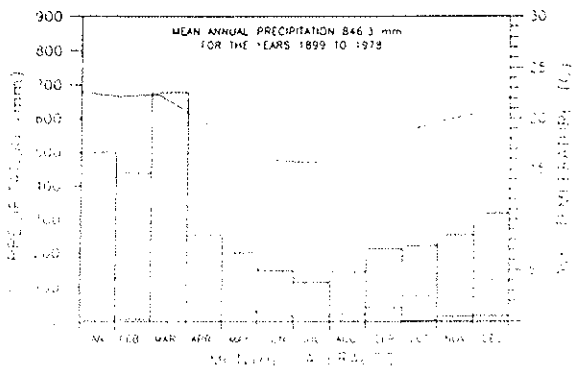


RAIN DAYS

SITEKI WEATHER STATION (44)



TEMPERATURE AND PRECIPITATION



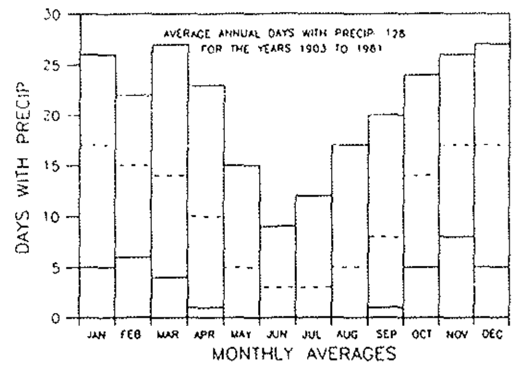
NOTES:
1) STATIONS WERE SELECTED ON THE BASIS OF LENGTH OF RECORD AVAILABLE AND GEOGRAPHIC LOCATION
2) LENGTHS OF RECORDS ARE INDICATED IN EACH HISTOGRAM THESE RANGE FROM 20 TO 79 YEARS (SITEKI).
3) SEE LOCATIONS OF CLIMATE STATIONS ON FIG. 8.

MONTHLY RAINFALL AND TEMPERATURE TRENDS FOR SELECTED STATIONS

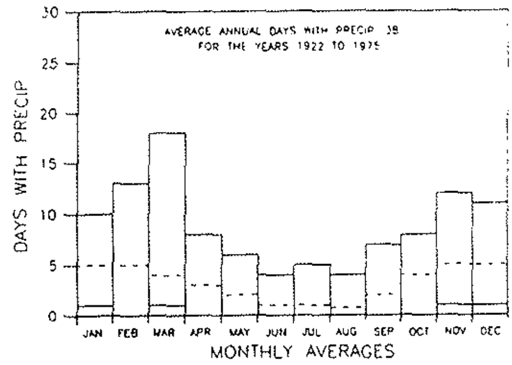
FIGURE: 11

RAIN DAYS

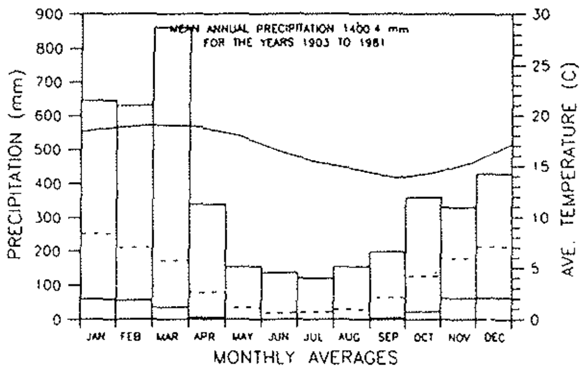
MBABANE WEATHER STATION (29)

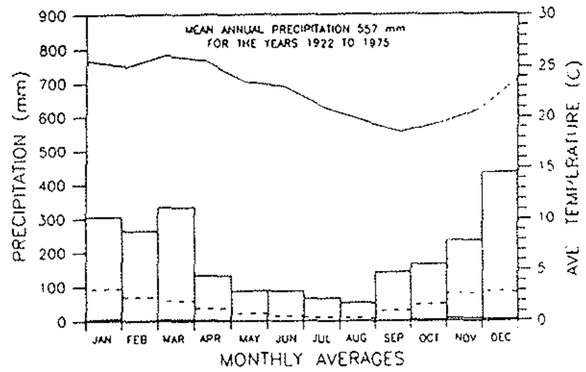


BIG BEND WEATHER STATION (64)

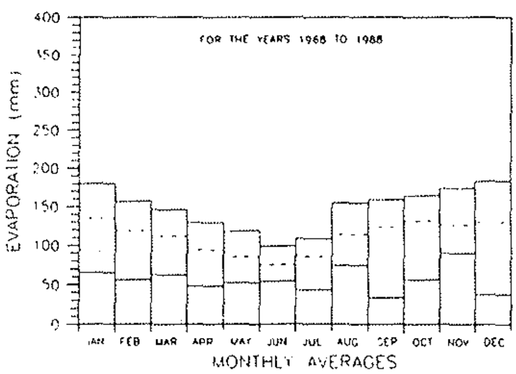


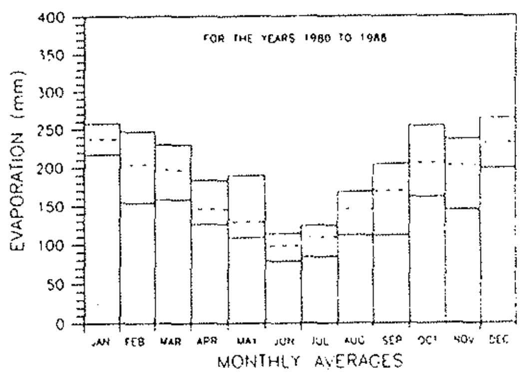
TEMPERATURE AND PRECIPITATION

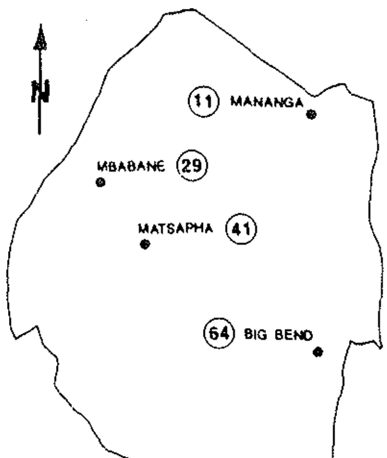


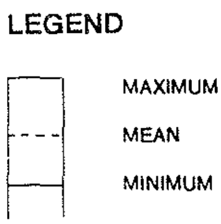


CLASS A PAN EVAPORATION



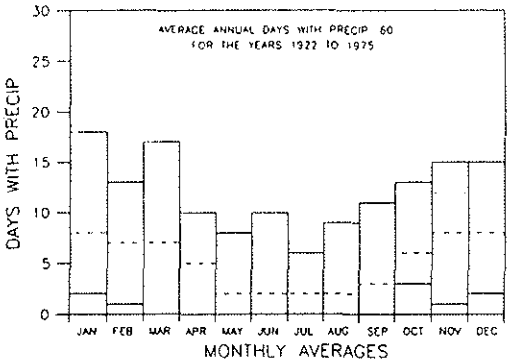




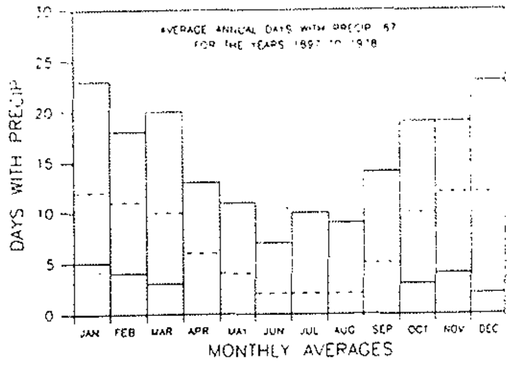


RAIN DAYS

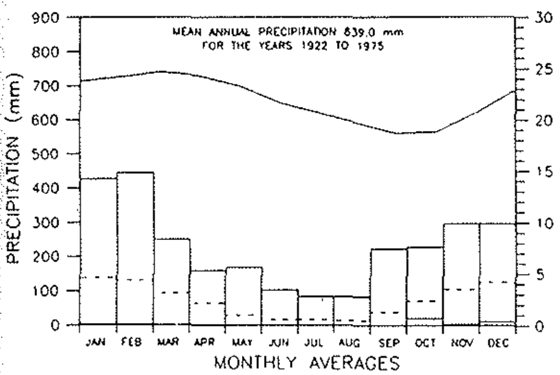
MANANGA WEATHER STATION (11)

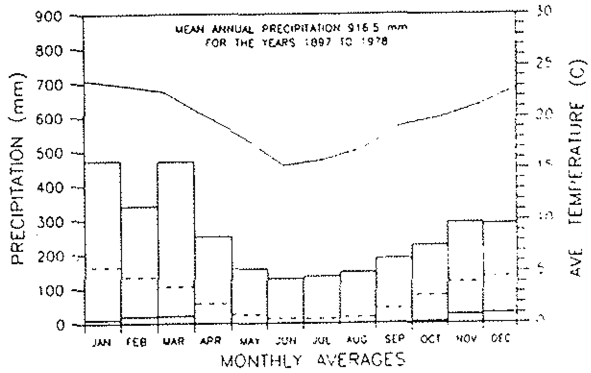


MATSAPHA WEATHER STATION (41)

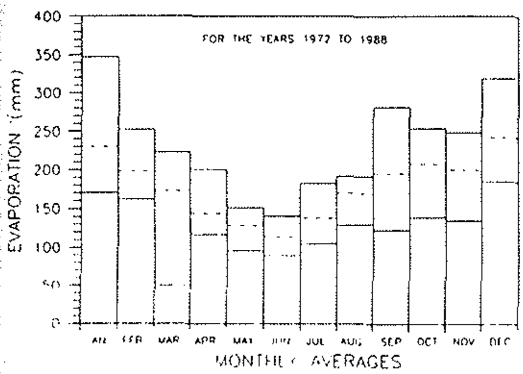


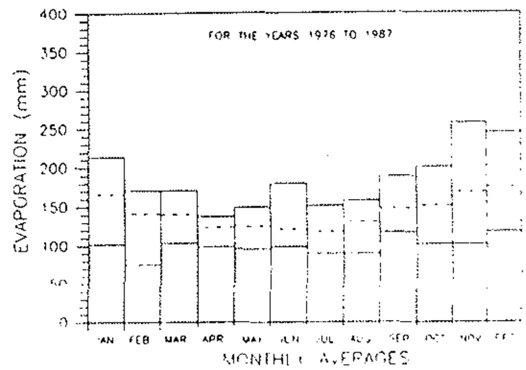
TEMPERATURE AND PRECIPITATION





CLASS A PAN EVAPORATION



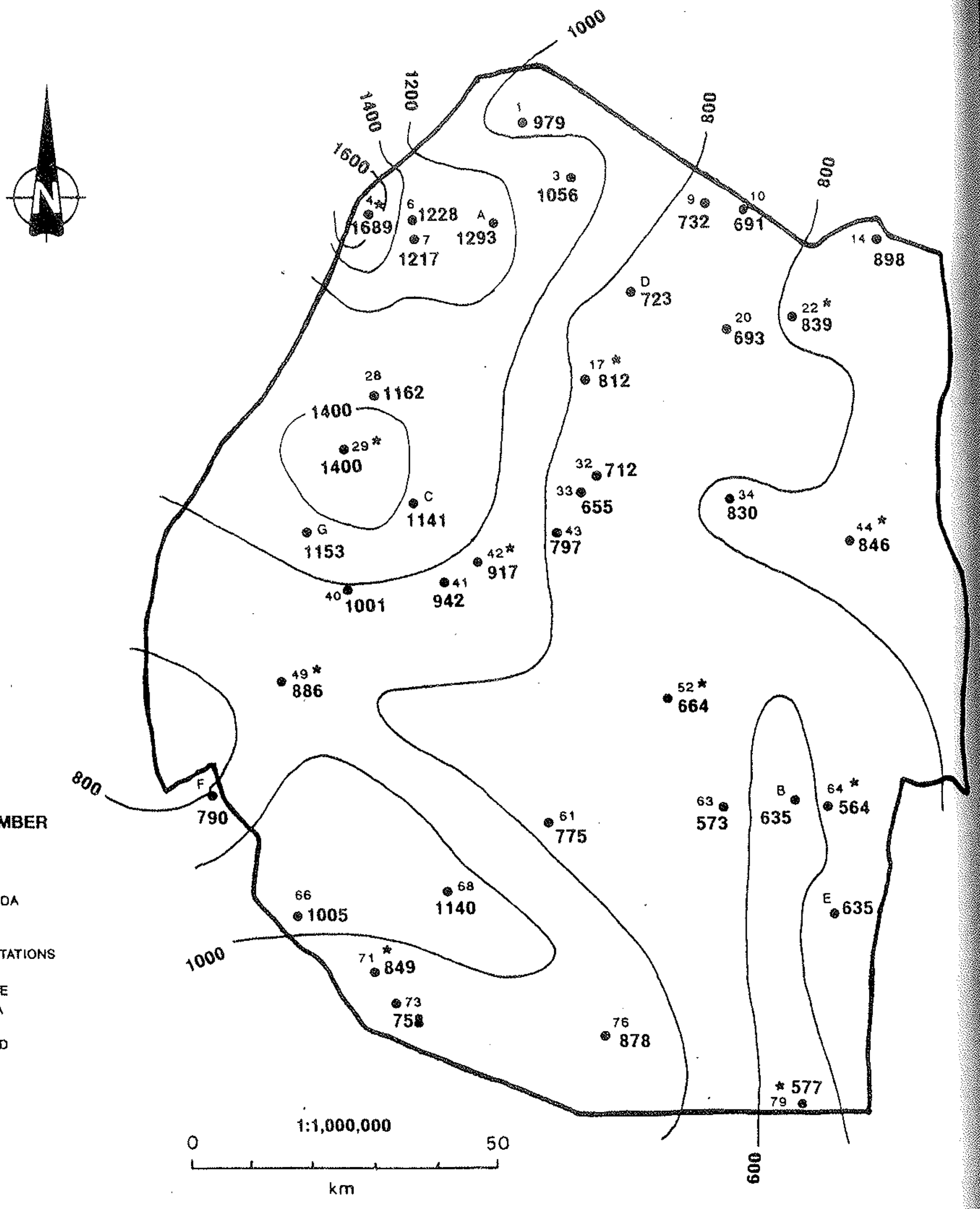


NOTES:

1) STATIONS WERE SELECTED ON THE BASIS OF LENGTH OF RECORD AVAILABLE AND GEOGRAPHIC LOCATION
2) LENGTHS OF RECORDS ARE INDICATED IN EACH HISTOGRAM. THESE RANGE FROM 8 TO 81 YEARS (MATSAPHA / MANZINI).
3) DATA FOR MATSAPHA AND MANANGA STATIONS HAVE BEEN SUPPLEMENTED BY DATA FROM NEARBY MANZINI AND VUVULANE STATIONS, RESPECTIVELY.
4) SEE LOCATIONS OF CLIMATE STATIONS ON FIG. 8.

MONTHLY RAINFALL, EVAPORATION AND TEMPERATURE TRENDS FOR SELECTED STATIONS

FIGURE: 12



STATION NUMBER & NAME

1 NGONINI
3 MAYIWANE RDA
4 BULEMBU
6 PIGGS PEAK
7 SWAZI PLANTATIONS
9 TUNZINI
10 BORDERGATE
14 LOMAHASHA
17 FOYERS
20 HOMESTEAD
22 VUVULANE
28 MBULUZI
29 MBABANE
32 DINEDOR
33 MPISI I
34 MPAKA
40 MALKERNS
41 MATSAPHA
42 MANZINI
43 ST.JOSEPH
44 SITEKI
49 MANKAYANE
52 SIPHOFANENI
61 KUBUTA
63 ST.PHILLIPS
64 BIG BEND
66 JOHANNESLOOP
68 HLATIKULU
71 NHLANGANO
73 DWALENI
76 HLUTI
79 LAVUMISA

A McCORKINDALE
B CROOKE'S PLANTATIONS
C McCREEDY
D BHOLEKANE
E CANTERBURY
F WELLEVVEDEN
G ORRIN

LEGEND

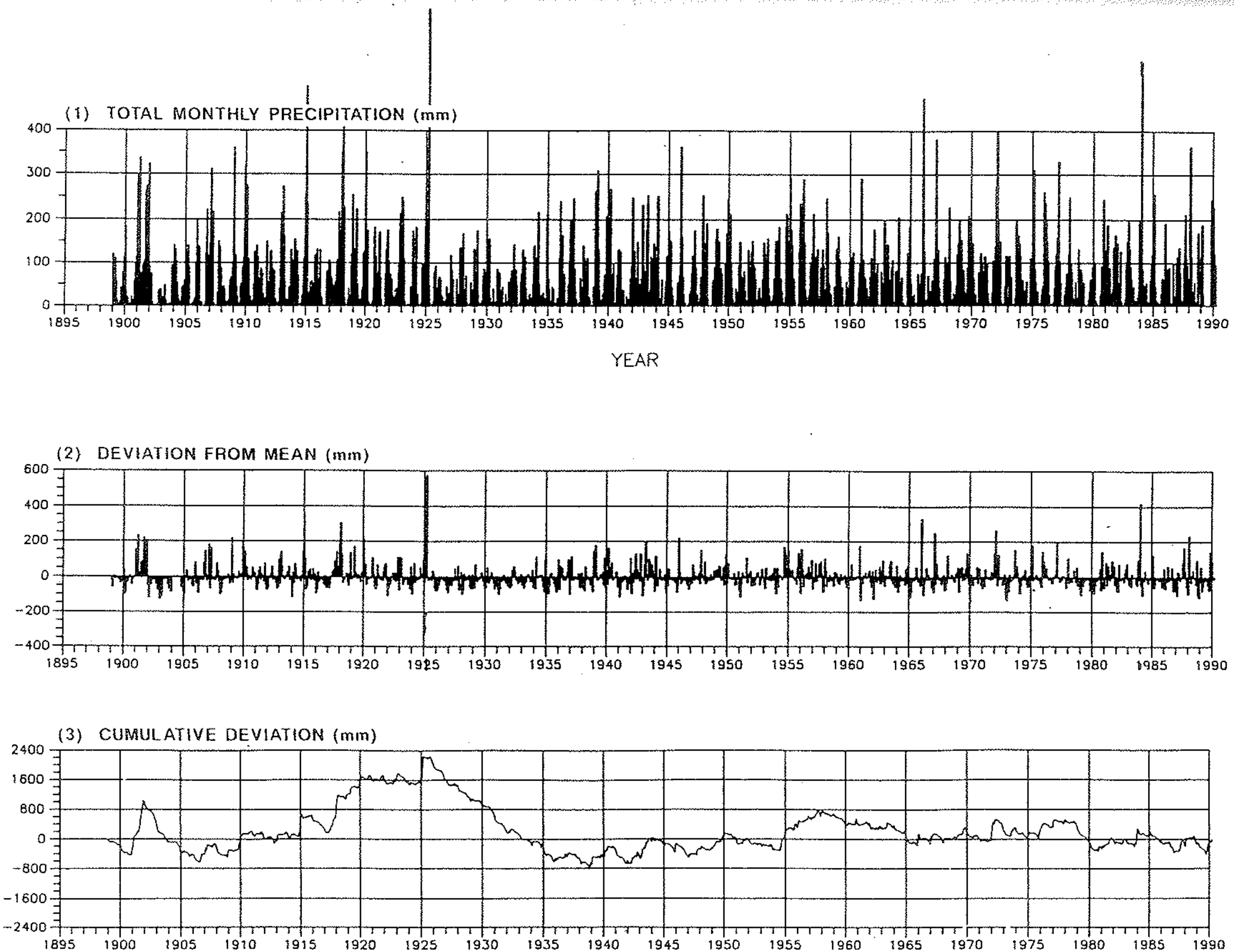
● METEOROLOGICAL STATION
* MONTHLY AVERAGE SUMMARY AND PLOTS PRESENTED
——1000 AVERAGE ANNUAL ISOHYET (mm)

NOTE: Station numbers follow scheme used in MacDonald report.
Results for lettered stations shown are from various other sources.

AVERAGE ANNUAL RAINFALL ISOHYETS

FIGURE: 13

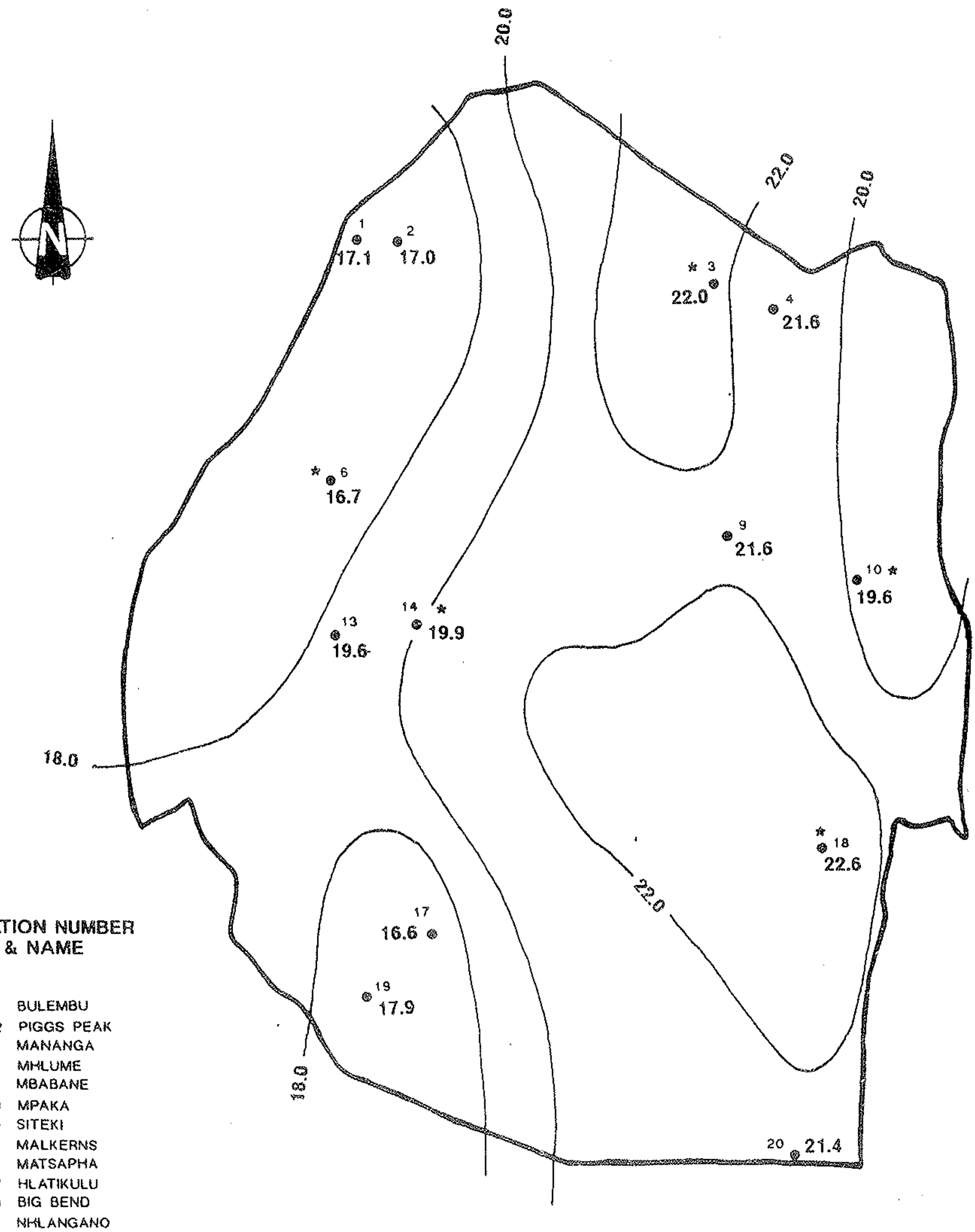
CUSUM TRENDS FOR MONTHLY RAINFALL AT SITEKI



NOTES:

1) DEVIATIONS CALCULATED FROM EACH OF THE TWELVE MONTH MEANS.
2) SEE LOCATION OF CLIMATE STATION (NO. 10) ON FIG. 8.

FIGURE: 14



STATION NUMBER & NAME

1 BULEMBU
2 PIGGS PEAK
3 MANANGA
4 MHLUME
6 MBABANE
9 MPAKA
10 SITEKI
13 MALKERNS
14 MATSAPHA
17 HLATIKULU
18 BIG BEND
19 NHLANGANO
20 LAVUMISA

LEGEND

⊗ METEOROLOGICAL STATION
☆ MONTHLY AVERAGE SUMMARY AND PLOTS PRESENTED
—— 18.0 AVERAGE ANNUAL ISOHYET (°C)

1:1,000,000

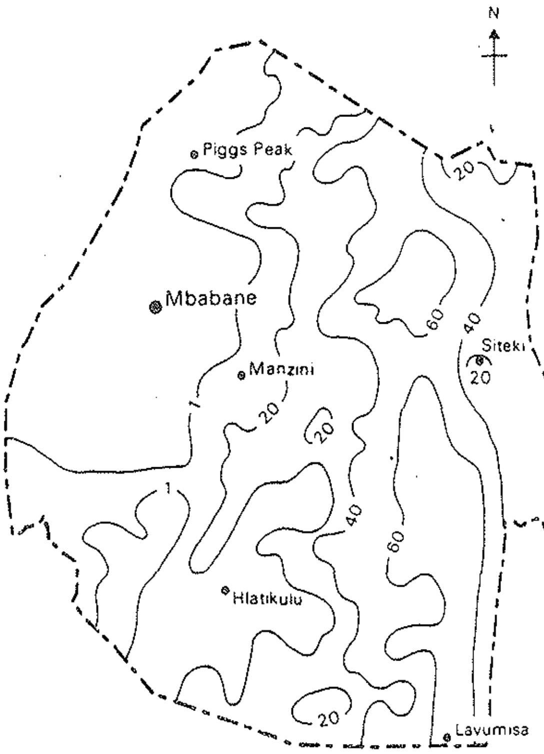
0 50
km

NOTES:

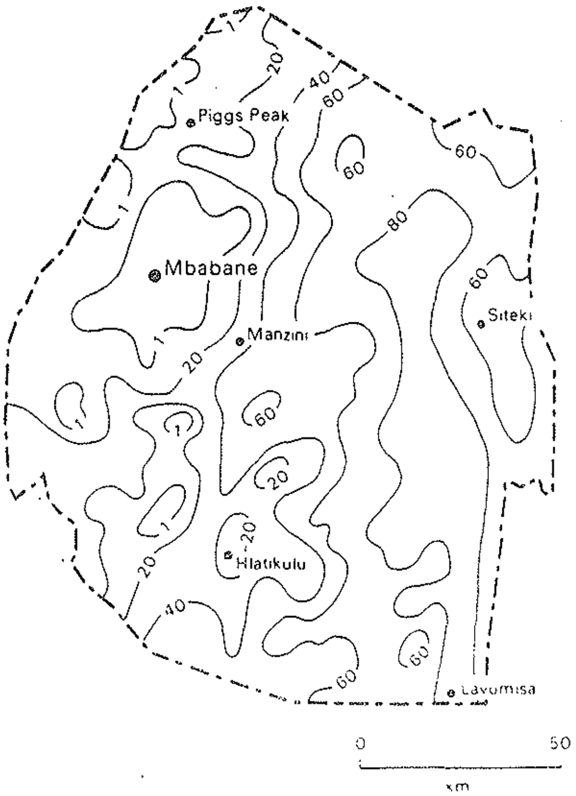
1) ALL INFORMATION IS BASED ON PRE-1987 METEOROLOGICAL DATA PROVIDED BY THE SWAZILAND DEPARTMENT OF WATER RESOURCES.
2) STATION NUMBERS FOLLOW SCHEME USED IN MACDONALD REPORT

AVERAGE ANNUAL TEMPERATURE ISOHYETS

FIGURE: 15

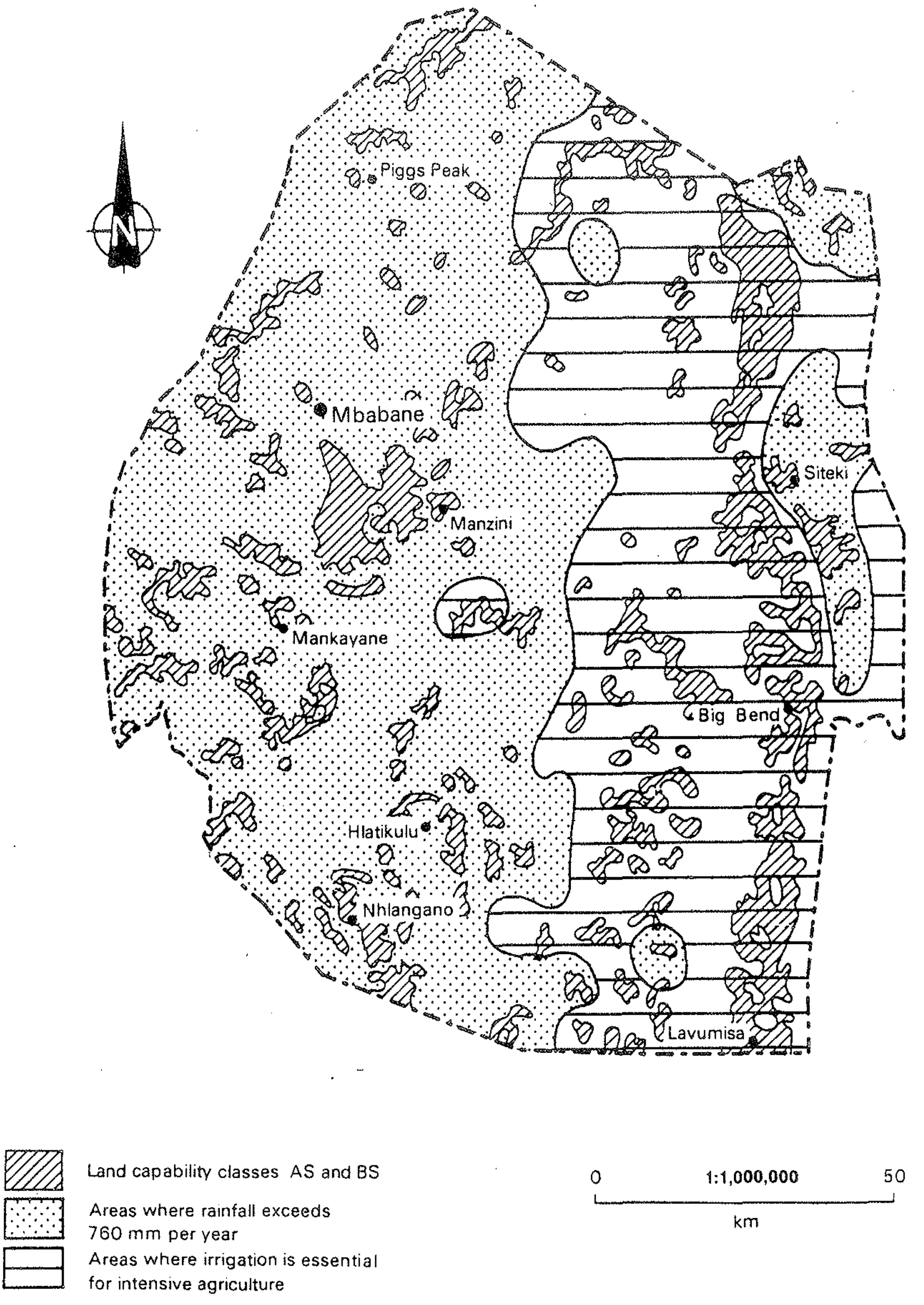


Percentage of summers receiving a rainfall of less than 508mm



Percentage of summers receiving a rainfall of less than 725 mm

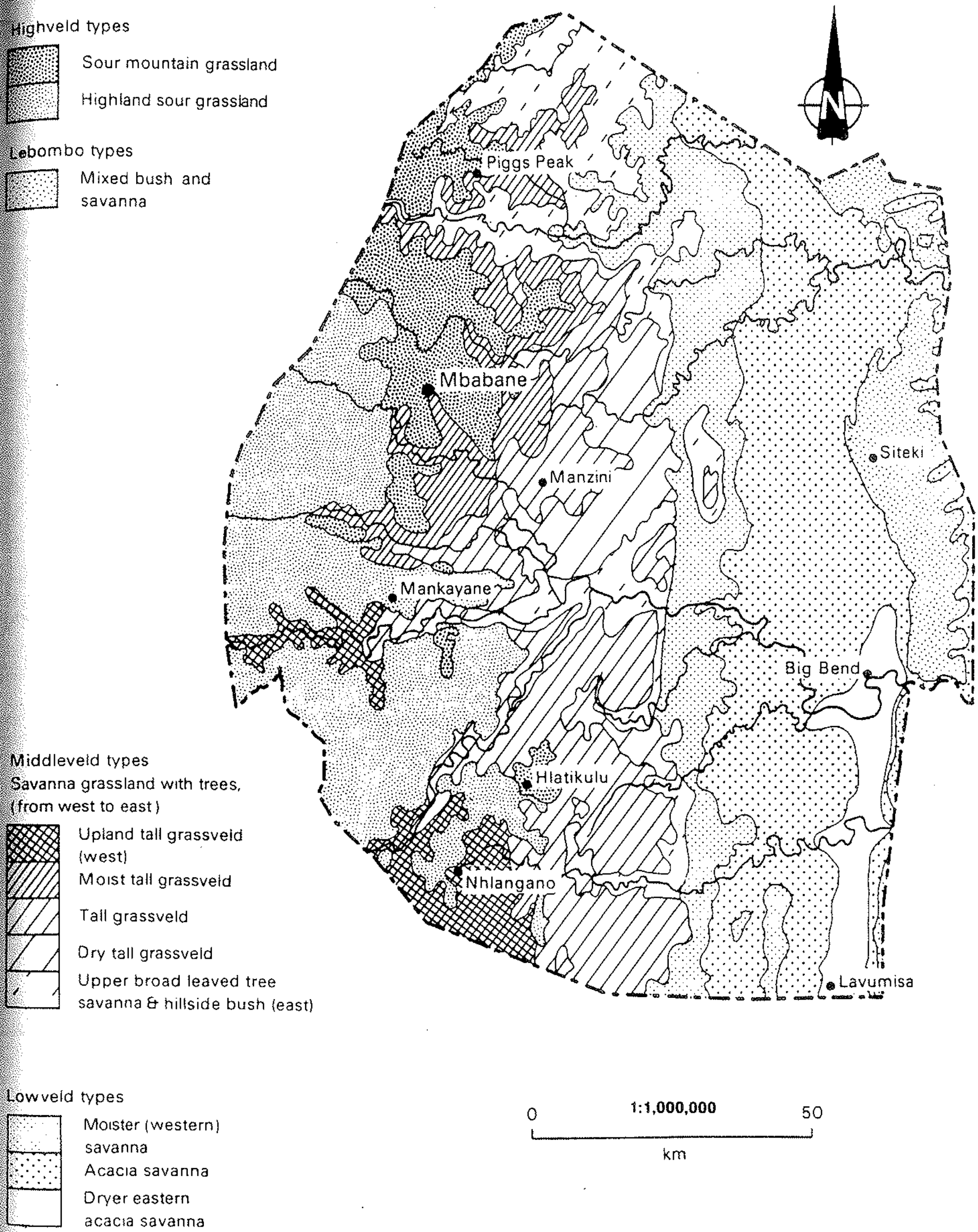
NOTE: Adapted from Goudie and Williams, 1983.



Note: Adapted from Goudie and Williams 1983.

LAND USE CAPABILITY

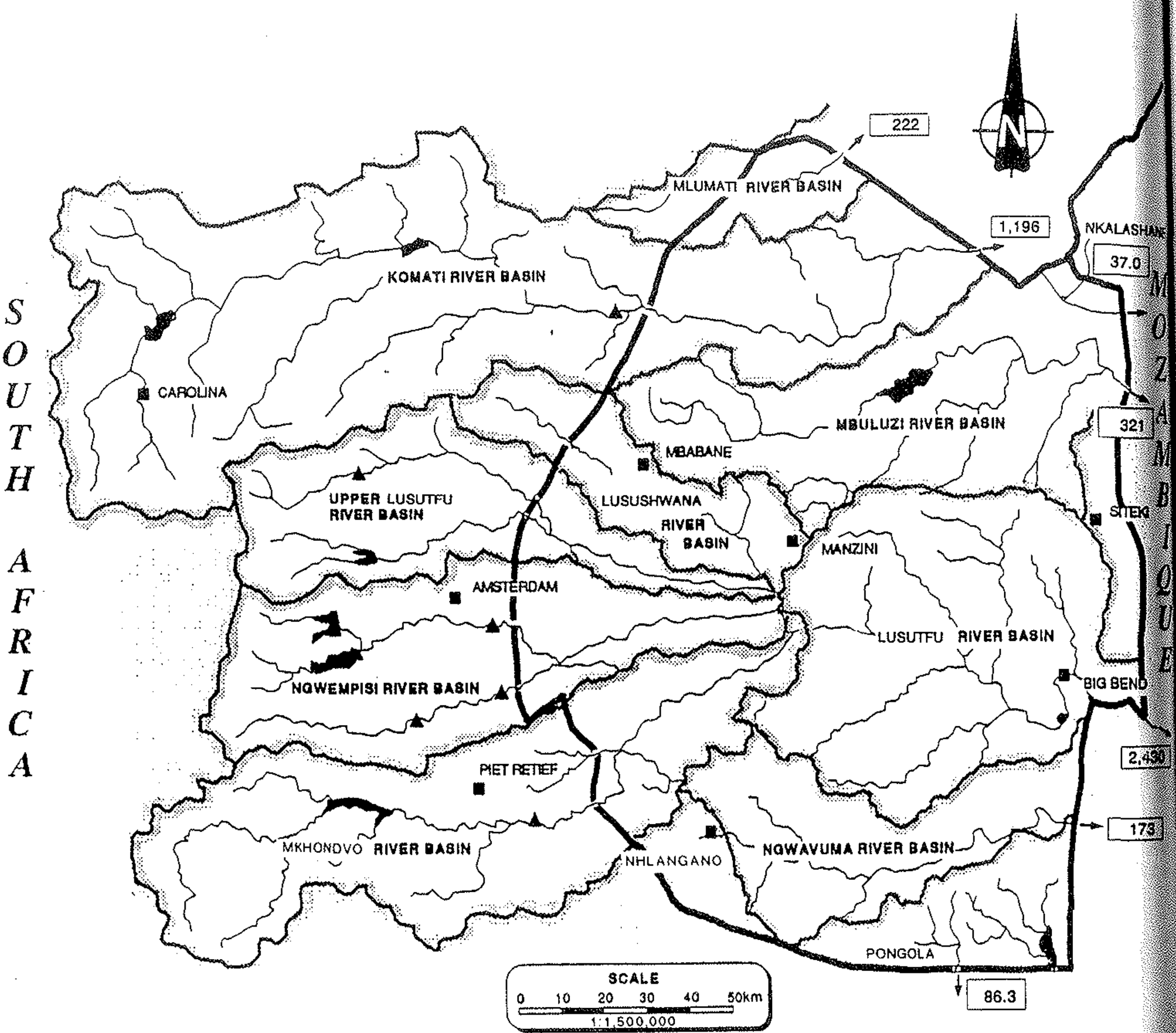
FIGURE: 17



Note: Adapted from Goudie and Williams 1983.

VEGETATION TYPES

FIGURE: 18



SUMMARY OF ESTIMATED ANNUAL SURFACE WATER RUNOFF (Mm³)

BASIN	INFLOW FROM SOUTH AFRICA	RUNOFF FROM SWAZILAND	OUTFLOW FROM SWAZILAND	PERCENT FROM SWAZILAND
KOMATI	727	469	1,196	39.2
LUSUTFU	1,073	1,357	2,430	55.8
MBULUZI	0	321	321	100.0
MLUMATI	74	148	222	66.7
MNZIMNYAMA	0	86	86	100.0
NGWAVUMA	0	173	173	100.0
PONGOLA	0	86	86	100.0
TOTAL	1,874	2,640	4,514	58.5

LEGEND

- Rivers
- Boundaries of Major River Basins
- International Boundaries
- Large Communities
- Potential Dam Sites
- Reservoir
- 321 Annual discharge (Millions of cubic metres).

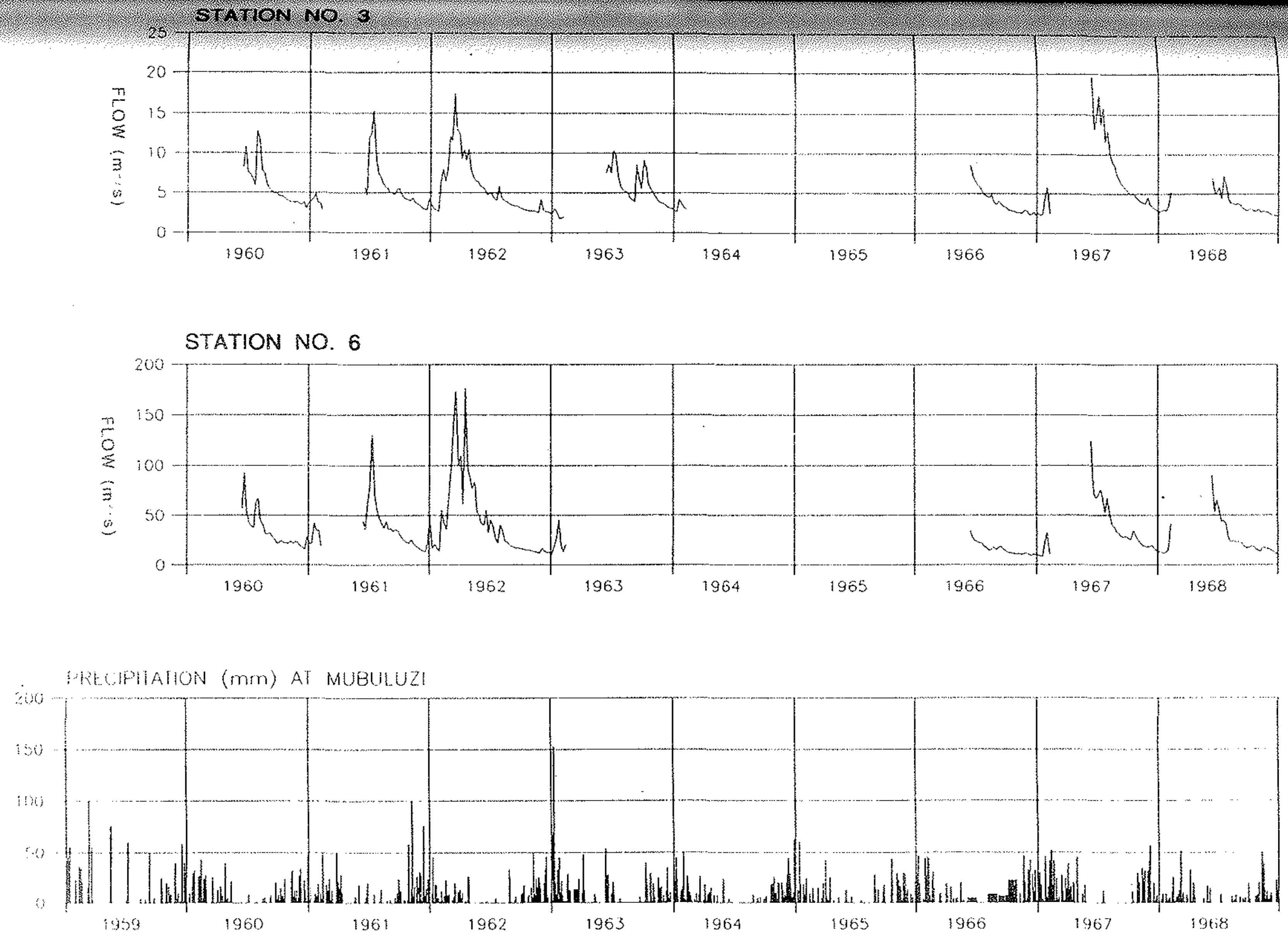
NOTES:

1) Modified from : MacDonald & Partners, 1990.
2) Numbers in boxes are undisturbed mean annual discharges in millions of cubic metres (Mm³).

RIVER BASINS AND DISCHARGES

FIGURE: 19

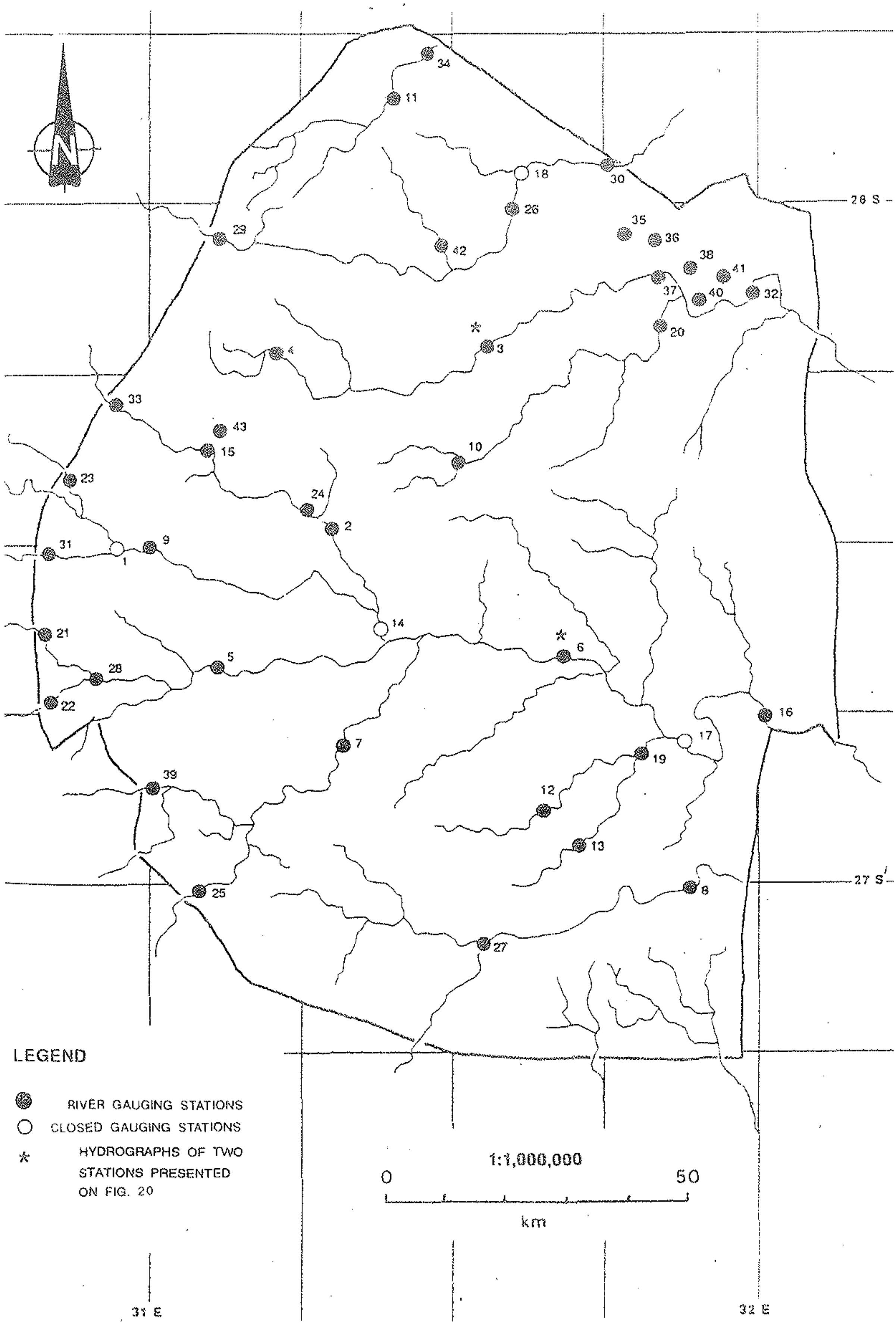
HYDROGRAPH OF LUSUTFU RIVER



NOTES:

1) GAPS IN THE RECORD INDICATE THAT DATA WAS NOT AVAILABLE.
2) SEE LOCATIONS OF FLOW GAUGING STATIONS ON FIG. 21

FIGURE: 20

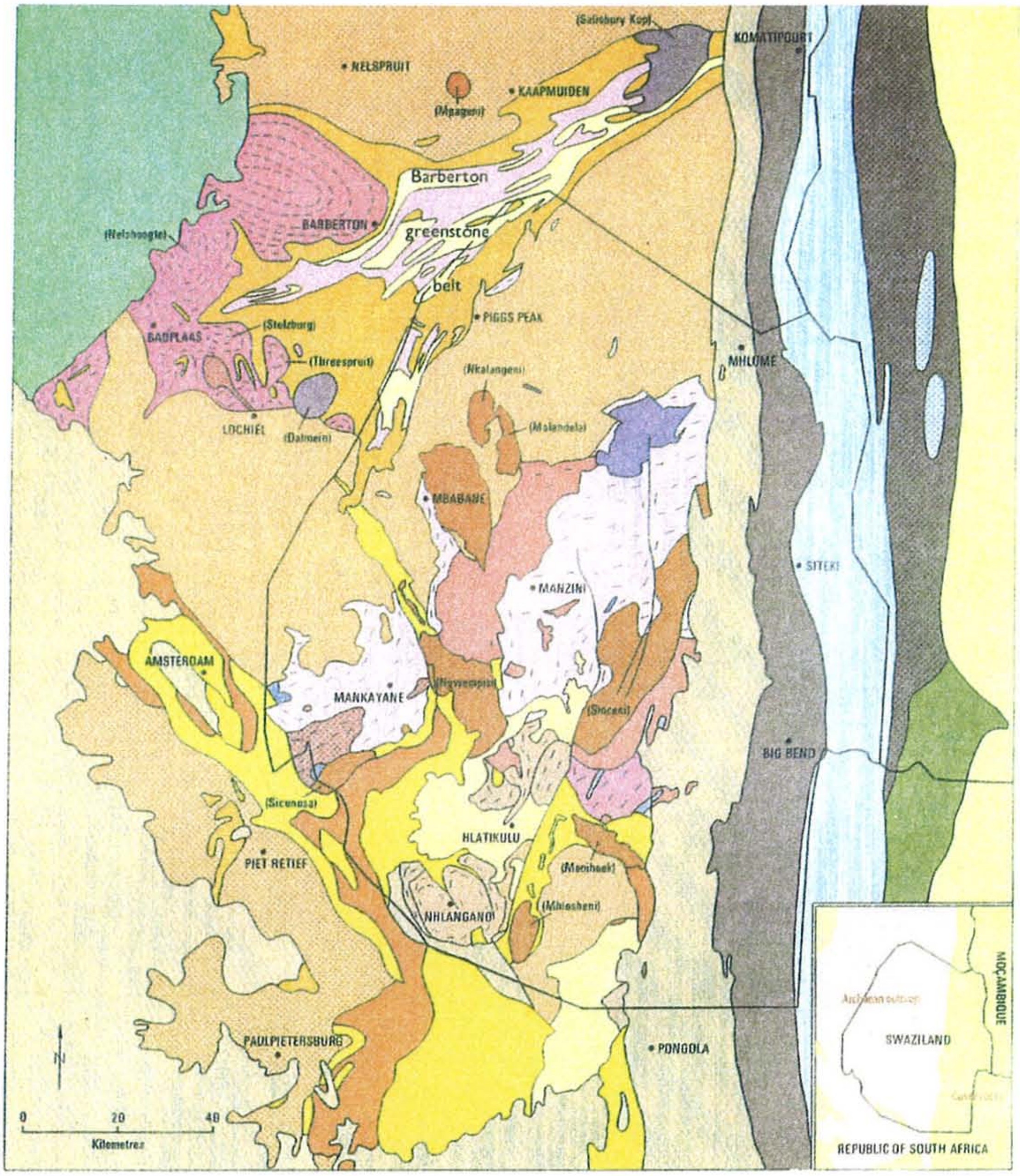


NOTES :

1) THIS FIGURE WAS ADAPTED FROM MacDONALD & PARTNERS LIMITED, JAN. 1990.

LOCATIONS OF PRINCIPAL RIVER GAUGING STATIONS

FIGURE: 21



LEGEND

- Quaternary
- Cretaceous

Karoo Supergroup

- Silica Beds (upper rhyolites)
- Moveni Basalts
- LR Lebombo Rhyolites
- BA Sabie River Basalt
- KE Ecca Group of Karoo Sediments
- Towns

Proterozoic / Palaeozoic

- Transvaal Supergroup

Archean (Swaziland)

- Undifferentiated Granites, Tonalites and Gneisses
- G5 Mswati Granite (AG5)
- GR Other Granites
- GL Nhlangano Gneiss
- UC Usushwana Complex
- GM Mliba Granodiorite
- MZ Mozaan Group
- Foliation Trend Lines in Gneisses

Archean (Swaziland)

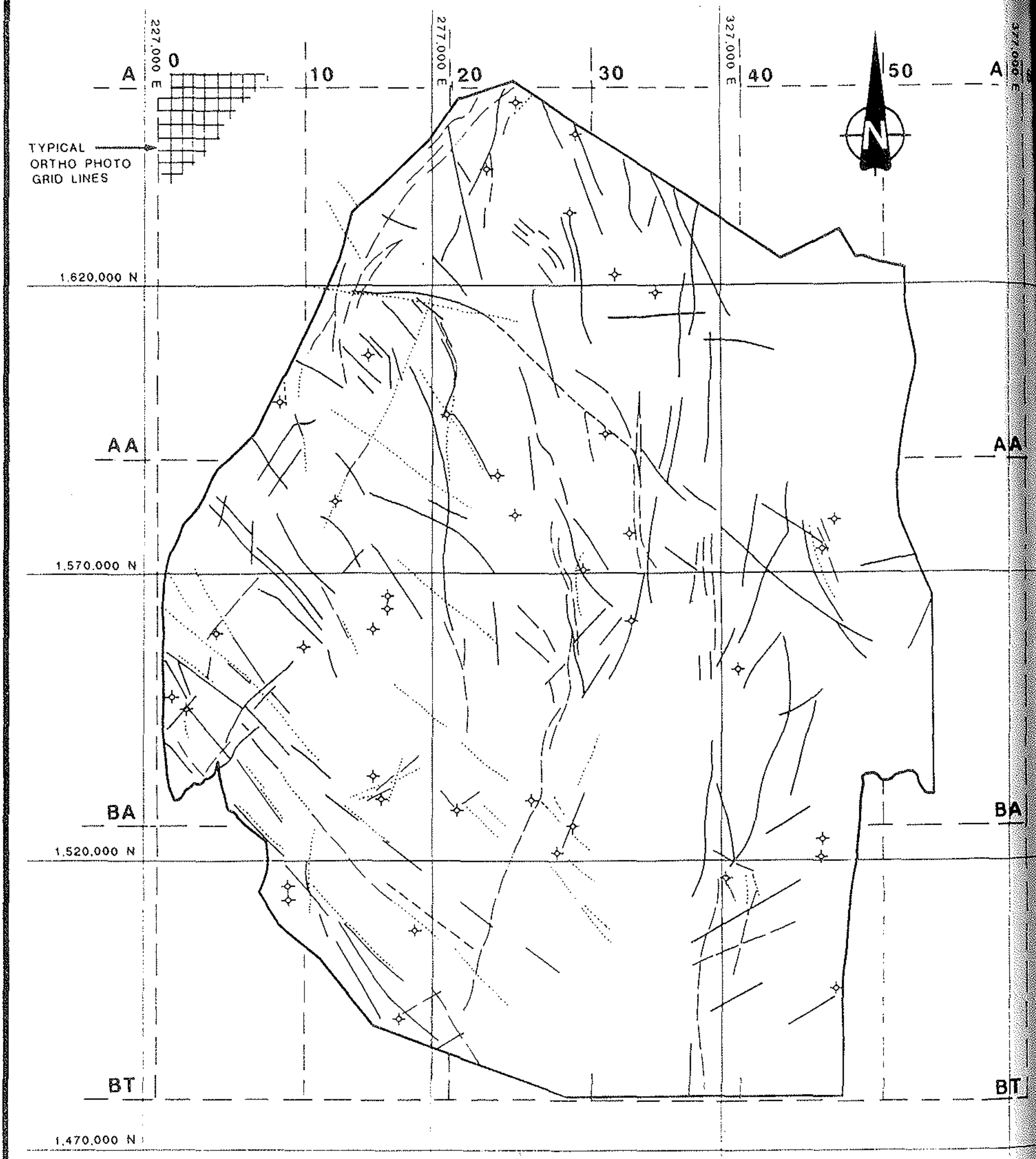
- I2 Insuzi Group
- G3 Lochiel Granite (AG3)
- GN Other Gneisses
- GD Granodiorite (Usutu Suite)
- GB Greenstone Belt Sediments and Lavas
- DW Dwalile Metamorphic Suite
- GW Ngwane Gneiss

Archean (Republic of South Africa

- Boesmanskop Syenite Pluton
- Trondhjemite Diapirs
- Hornblende Tonalite Diapirs
- Granodiorite Plutons (Dalmein, Sailsbury Kop)

NOTE: ADAPTED FROM WILSON 1982

SIMPLIFIED BEDROCK GEOLOGY MAP FIGURE:22



LEGEND

BOREHOLE WITH BLOWN YIELD GREATER THAN 4 L/s

LINEAMENTS DELINEATED FROM AIRBORNE MAGNETOMETER SURVEY

WELL DEFINED

INFERRED

LINEAMENTS CONFIRMED ON LANDSAT IMAGERY

WELL DEFINED

INFERRED

1:1000,000

0 10 20 30 40

km

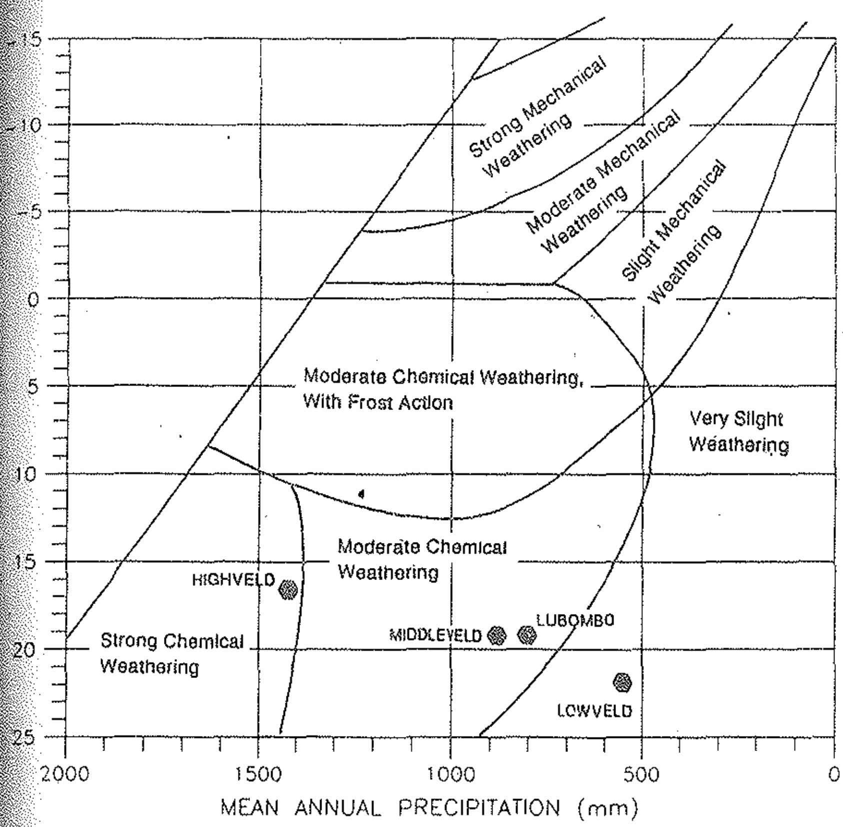
NOTES:

1) Airborne magnetometer survey data from Wilson 1982

2) Landsat data abstracted from Fig. 33, Piteau Associates, 198

BEDROCK LINEATION MAP

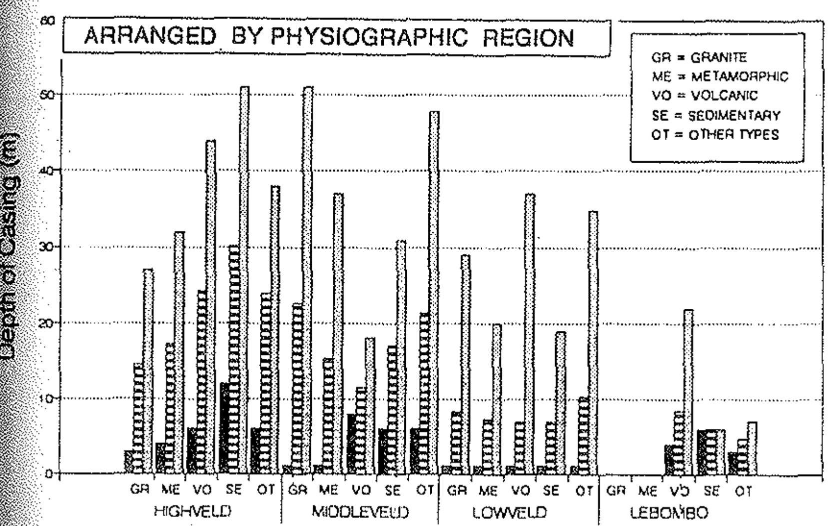
FIGURE: 23



Typical climatic values for four principal physiographic zones in Swaziland.

After Gidigasu, 1981.

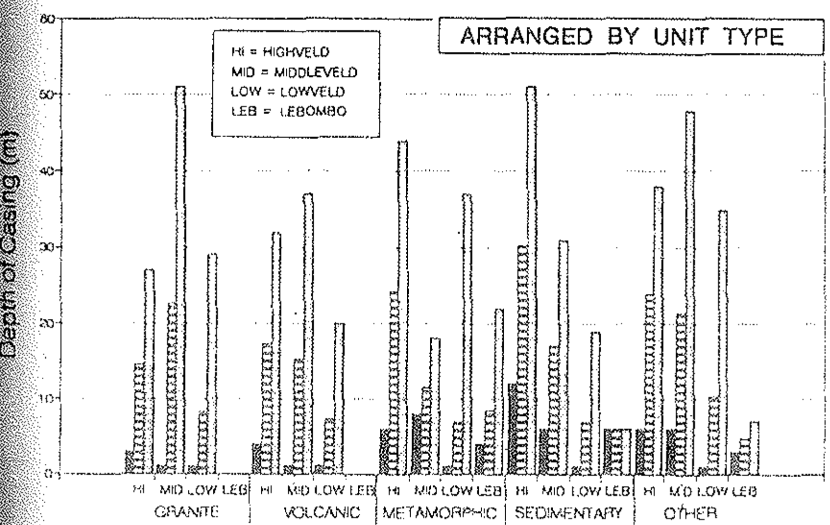
CASING DEPTH STATISTICS



Minimum

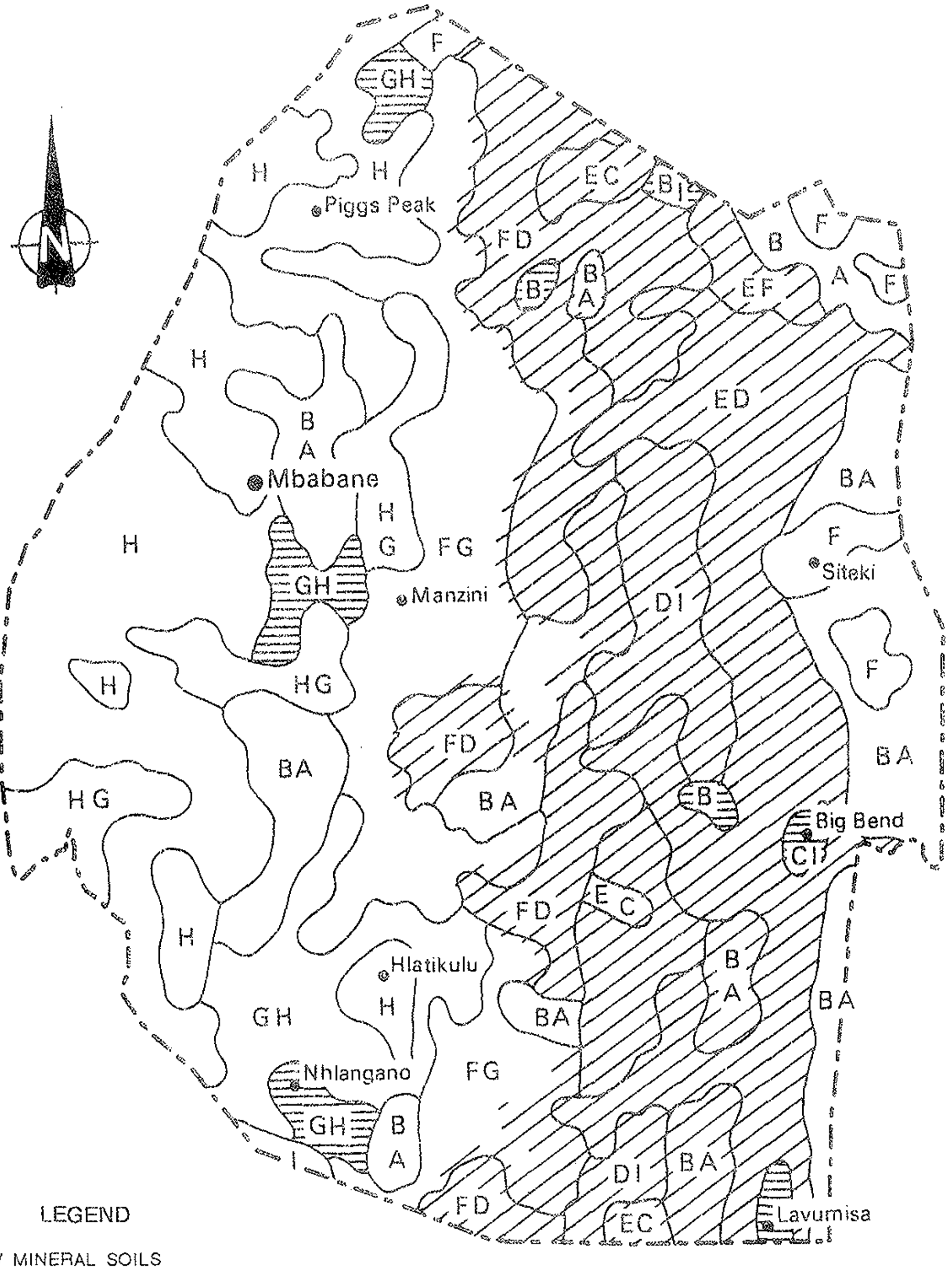
Average

Maximum



RELATIONSHIP BETWEEN CLIMATE AND WEATHERING

FIGURE: 24



LEGEND

A RAW MINERAL SOILS
B WEAKLY DEVELOPED SOILS
C VERTISOLS
D PSEUDOPODOSOLIC SOILS
E RED-BROWN SOILS OF THE SUB-ARID TROPICS
F FERISIALITIC SOILS
G FERRISOLIC KAOLISOLS
H FERRALITIC SOILS
I HALOMORPHIC SOILS

Areas where bottomland hydromorphic soils are usually calcareous & are often vertisols

Areas where soil types A & B are absent or rare; elsewhere common

1:1,000,000

0 50

km

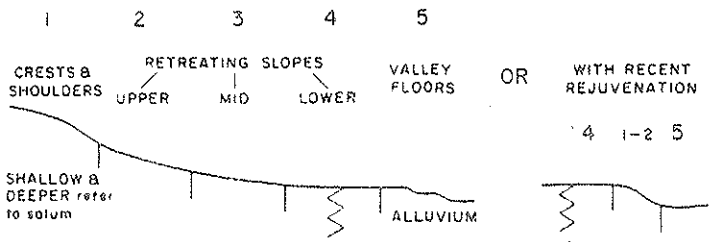
Note: Adapted from Goudie and Williams 1983

PRINCIPAL SOIL TYPES

FIGURE: 25

Stage of Weathering and Leaching Processess \ Permeability – An Expression of Pedoclimate		RAPID SHALLOW 1	RAPID DEEPER 1	RAPID 2	RAPID 3	RAPID 4	RAPID 5	GOOD SHALLOW 1	GOOD DEEPER 1	GOOD 2	GOOD 3	GOOD 4	GOOD 5
	T					PEDALFERS							
ACID ORGANIC	O	Darketown											
	T												
	O								Ngozi	Nduma			
	T					Ebede				Mxawo			
FERRALITIC	O	Oldrsef Ongeluk	Tatsni	Torgyle				Zayifu		Mfilane			
	T		Gubane			Enkulunyo							
	O	Outspan Orandweni		Qolweni	Qwabise		Bona	Sivulo Zombode	Songweni Madevu	Moorhoek Malkerns	Mdutshane Mbeli		[illegible]
	T									Ludomba			
FERSIALITIC	O	Omhlondlu Osaguleni		Orrin	Jovane Jakhi		Bushbaby	Stegi	Lutzi	Lesibovu Lomahasheni			[illegible]
	T											Nhloya	[illegible]
	O		‡ {					Sikhutwane Spekboom					
	T												
SIALITIC	O							Somerling Shebani					
	T												
	O												
	T												
HALOMORPHIC	O					PEDOCALS							
		1	1	2	3	4	5	1	1	2	3	4	5

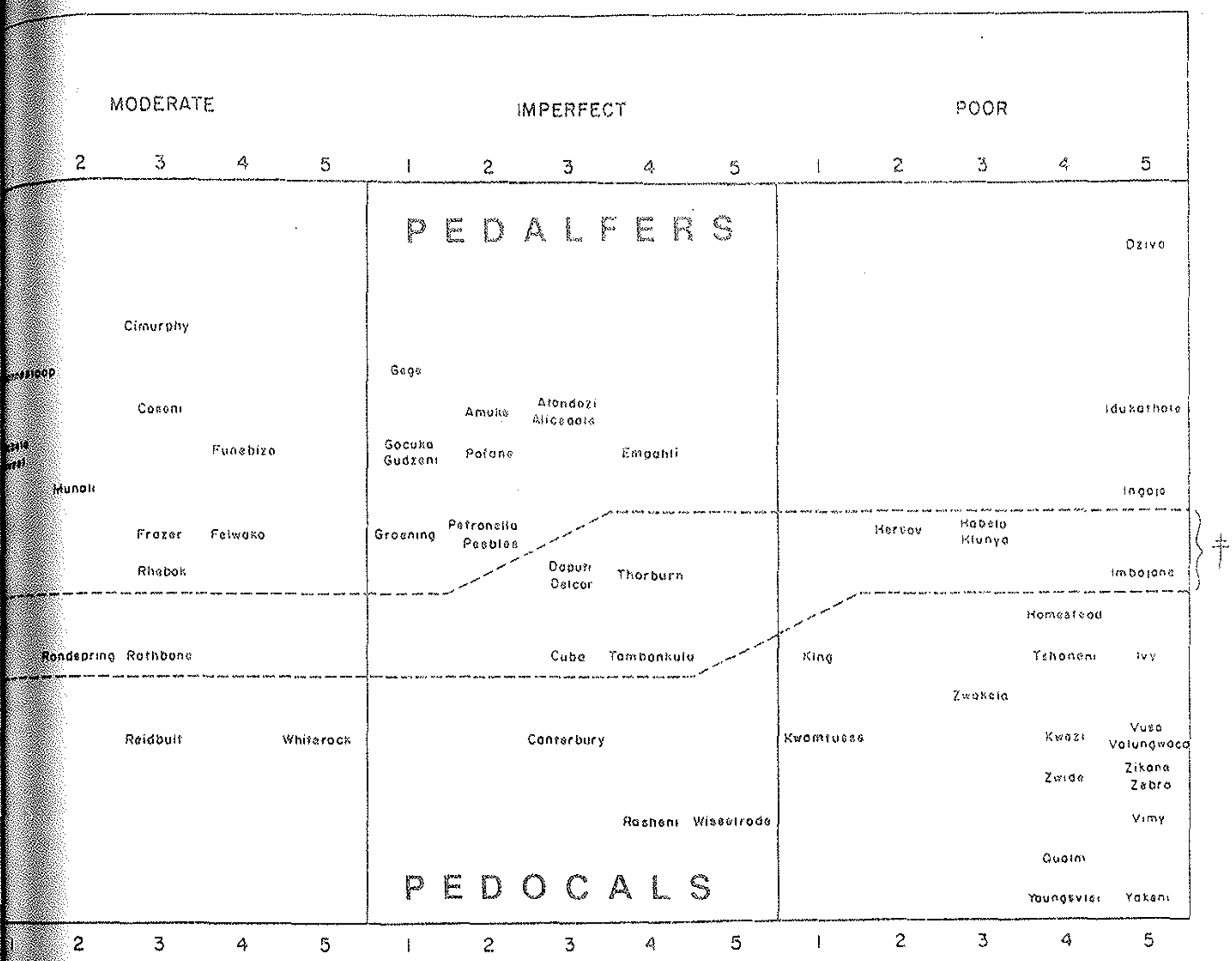
USUAL TOPOGRAPHIC SITUATION



NUMBER OF SERIES (TOTAL HERE 102)

PEDALFERS	64	SITE 1 SHALLOW	15	PERMY RAPID	19
PEDOCALS	23	1 DEEPER*	15	GOOD	27
TRANSITIONAL	15	2	19	MODERATE	14
		3	19	IMPERFECT	19
TWO-DECK	30	4	15	POOR	23
		5	19		

* All / soils with moderate to poor drainage are included



T = Two Deck

O = Other KINDS OF HORIZONATION

† PEDALFER – PEDOCAL TRANSITION BELT

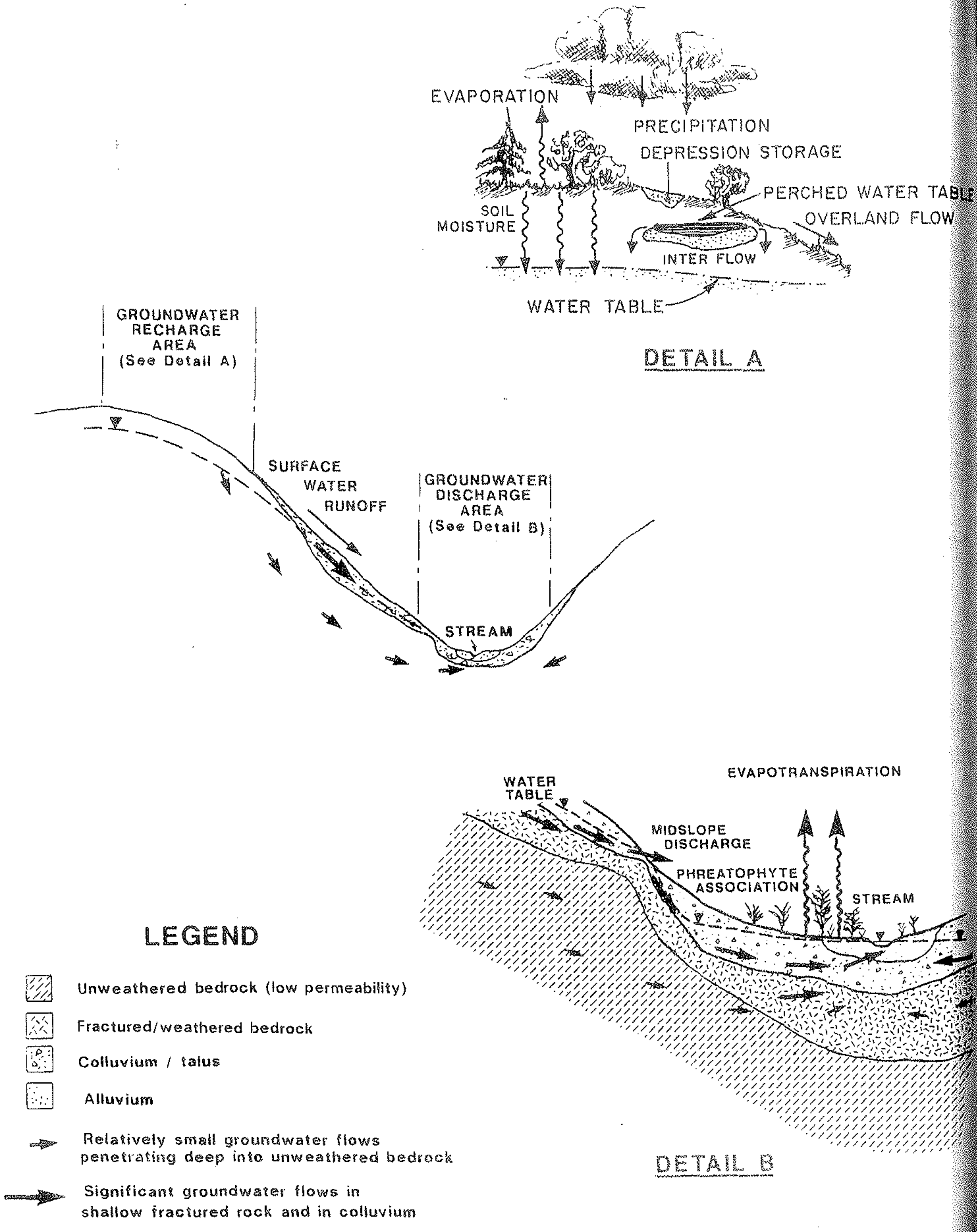
Series excluded: Gongola, Ungabolima, Umbeluzi, Upcountry and Xulwane.

NOTE: The modal placings of the series are shown; however, some may span a range, especially of positions on short slopes, so filling many apparent gaps in the grid.

Adapted from Murdoch (1972)

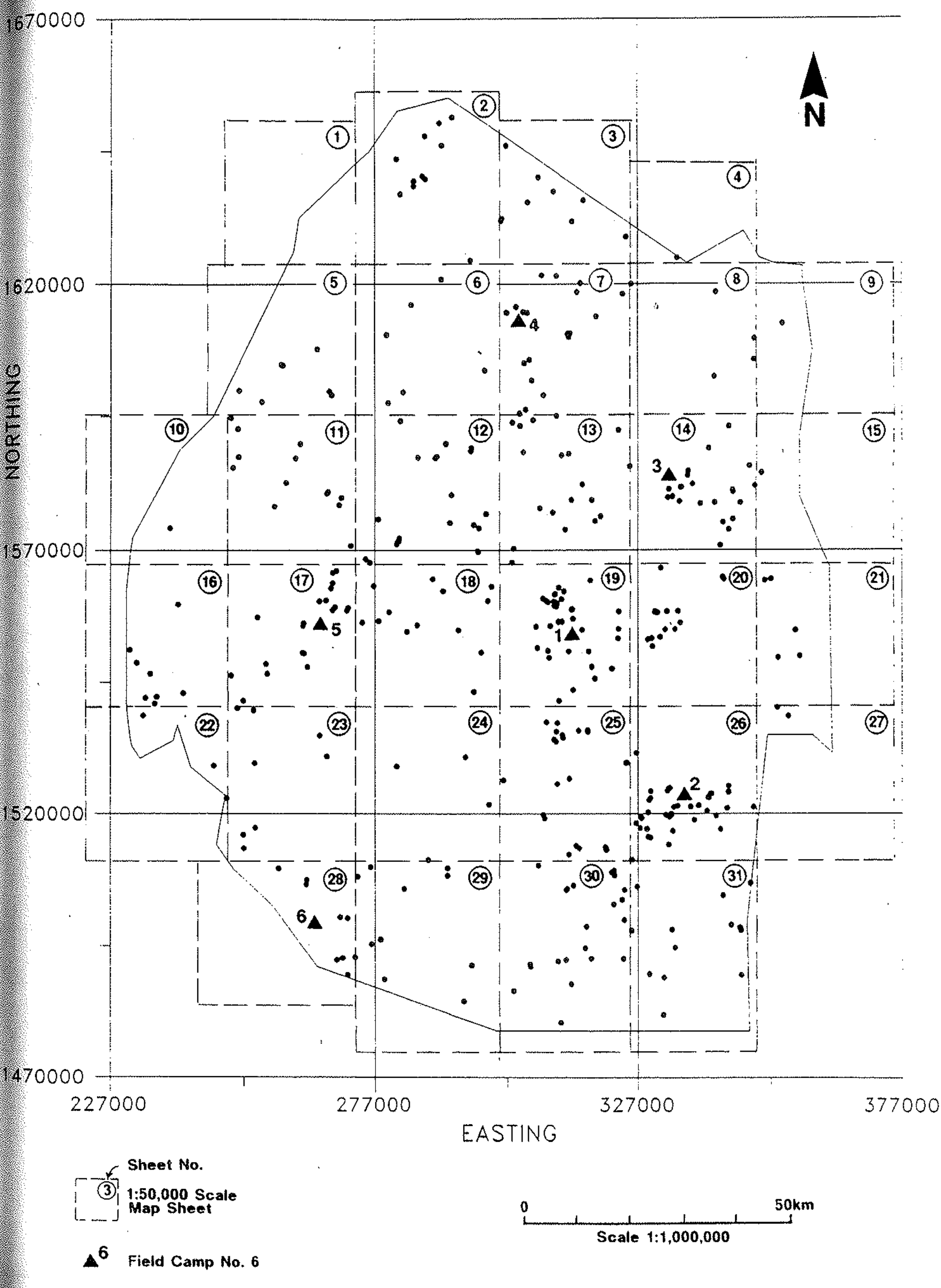
RELATIONSHIP BETWEEN TOPOGRAPHY, CHEMICAL LEACHING AND PERMEABILITY FOR SWAZILAND SOILS

FIGURE 26



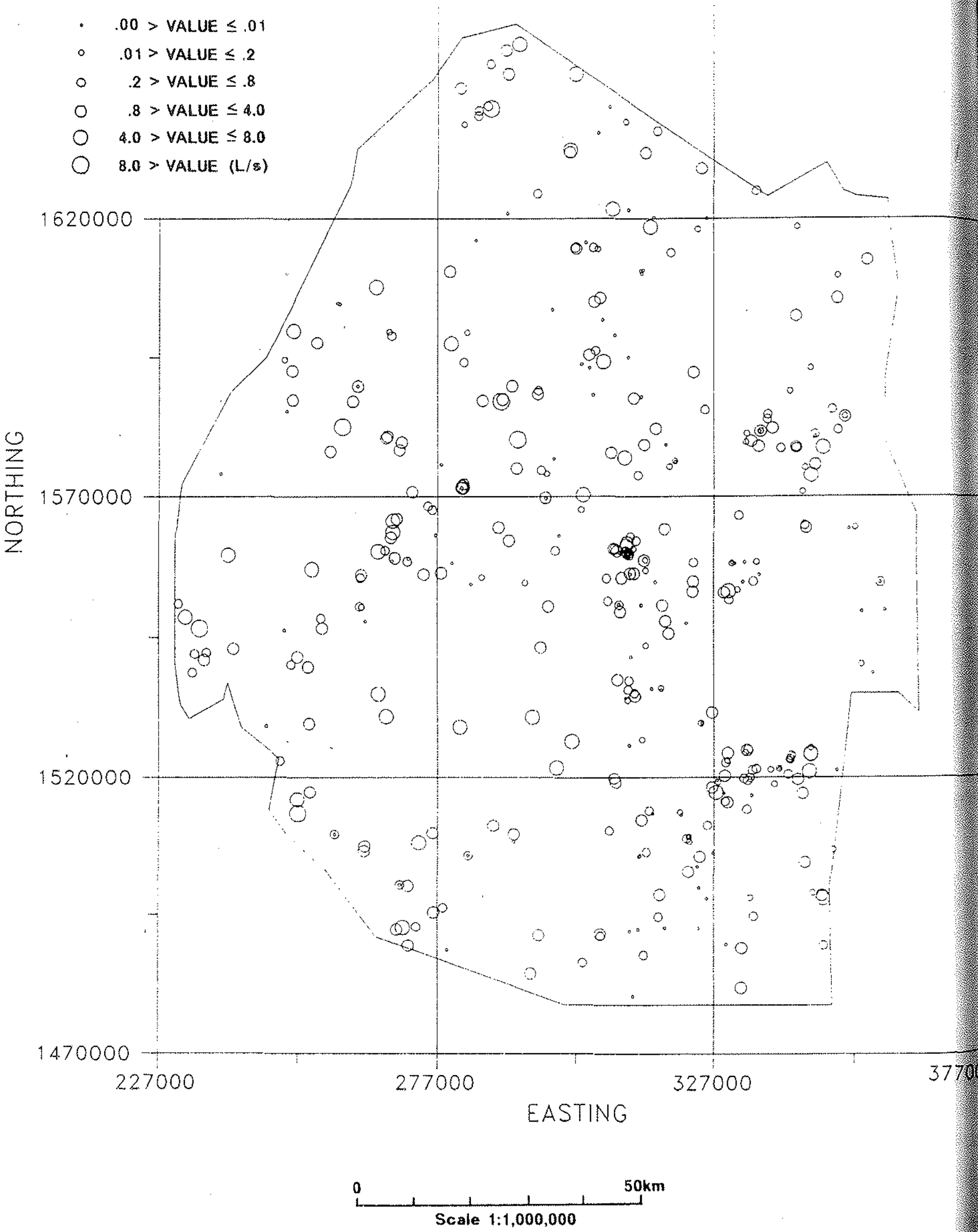
TYPICAL GROUNDWATER FLOW SYSTEMS IN MOUNTAINOUS AREAS

FIGURE: 2



LOCATIONS OF PROJECT BOREHOLES AND MAPSHEETS

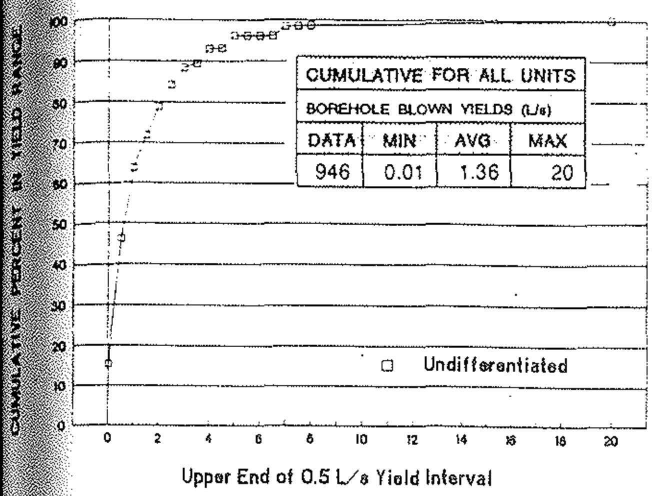
FIGURE: 28

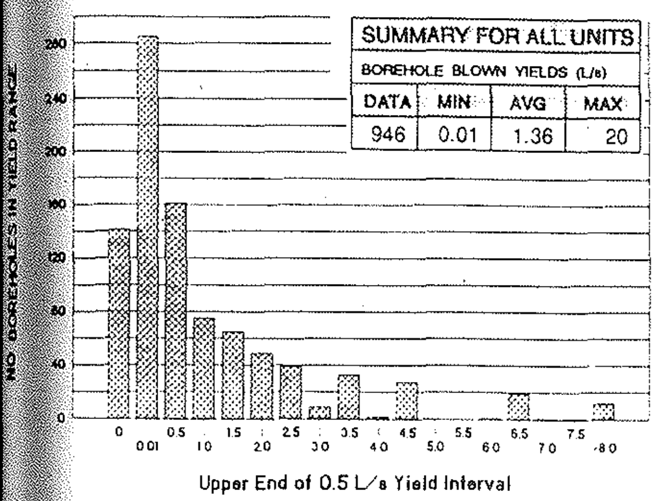


PROJECT BOREHOLE YIELDS:
MAGNITUDE AND DISTRIBUTION

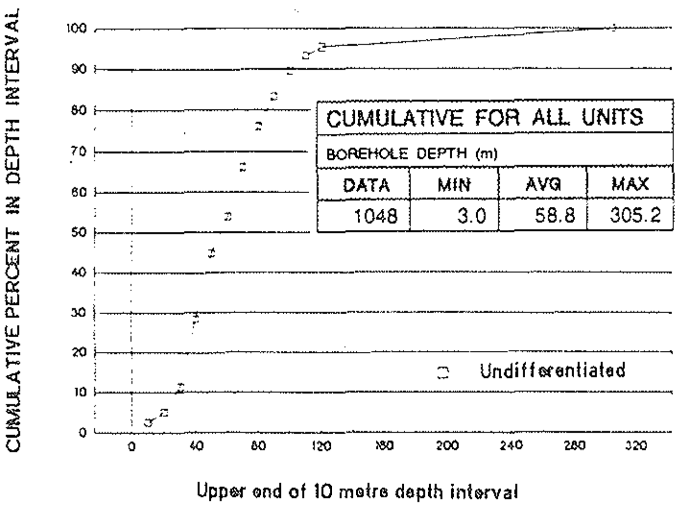
FIGURE: 2

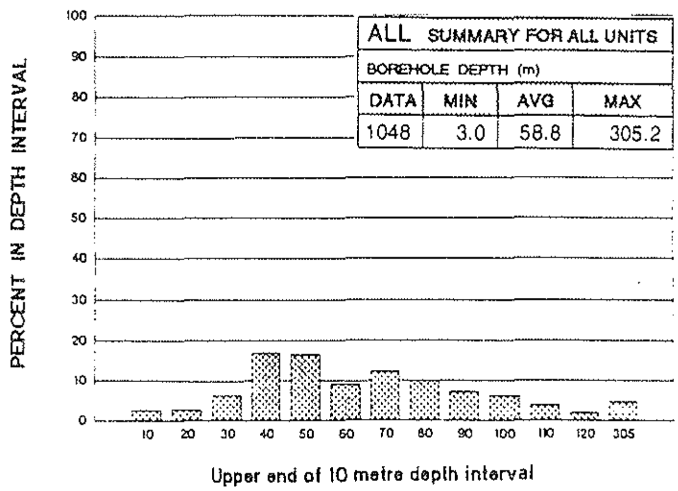
YIELDS





DEPTHS

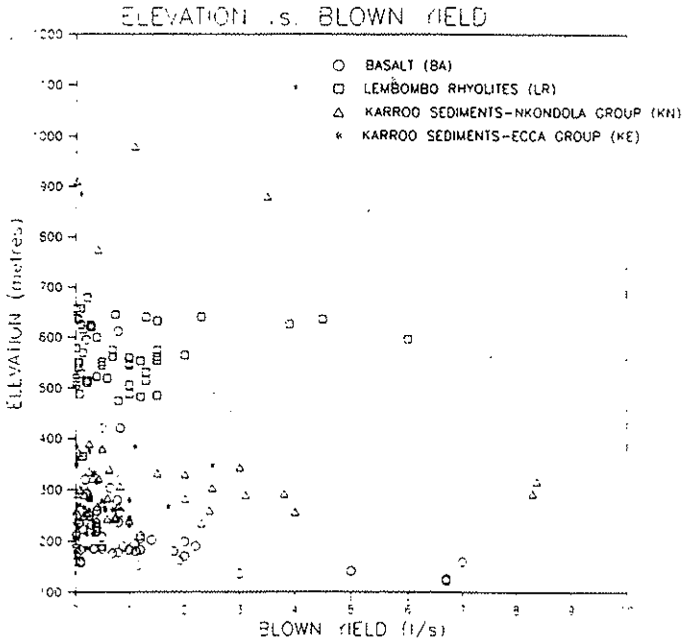


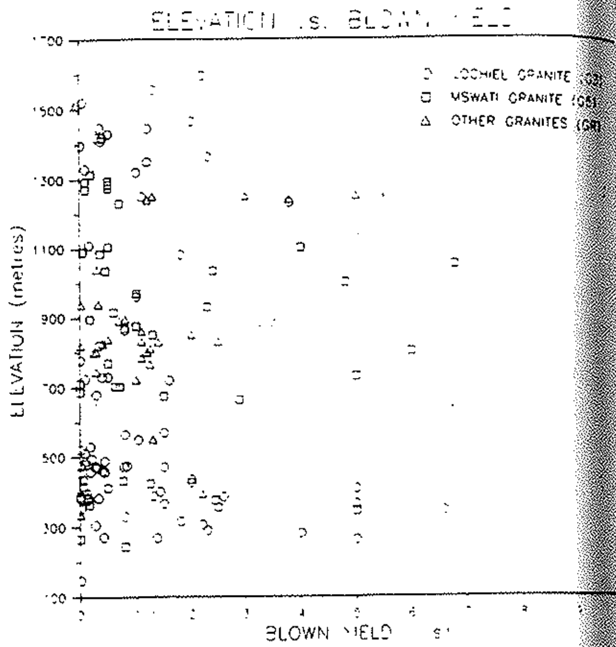


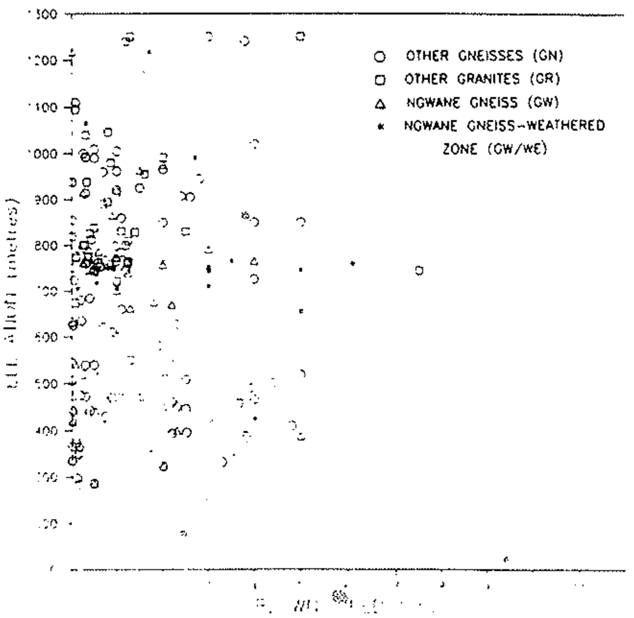
NOTES:

1) Only hydrogeological units with more than six sets of data are represented in the graphs.
2) For more information on the units, see data on Tables II, III and IV.
3) Blown yields indicated above were estimated at the time of of drilling and may not reflect true sustainable yields.

BLOWN YIELDS AND DEPTHS OF BOREHOLES | FIGURE: 30

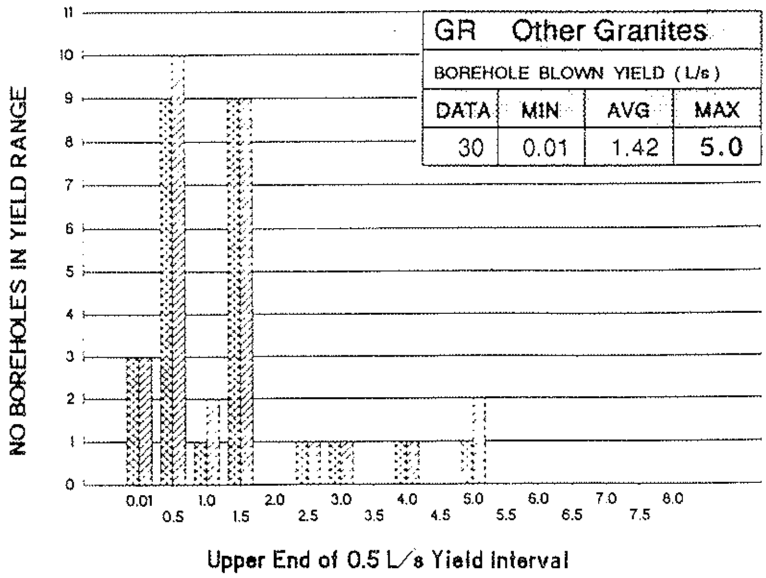


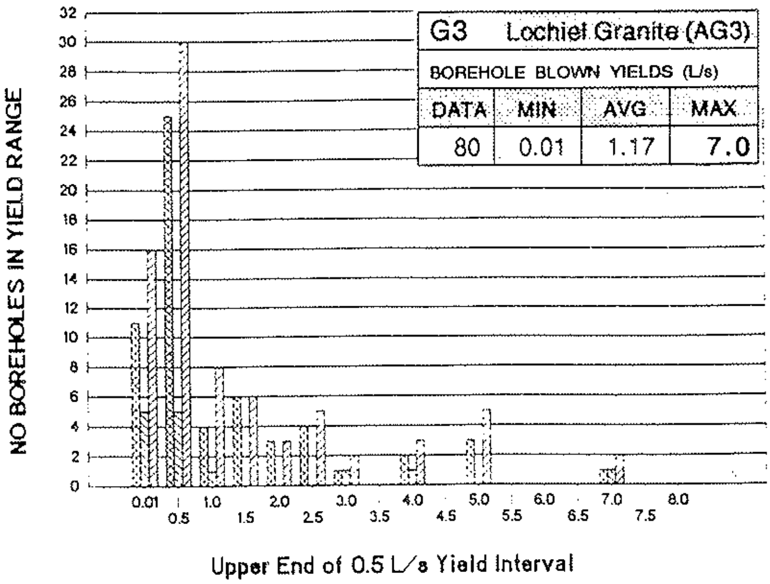


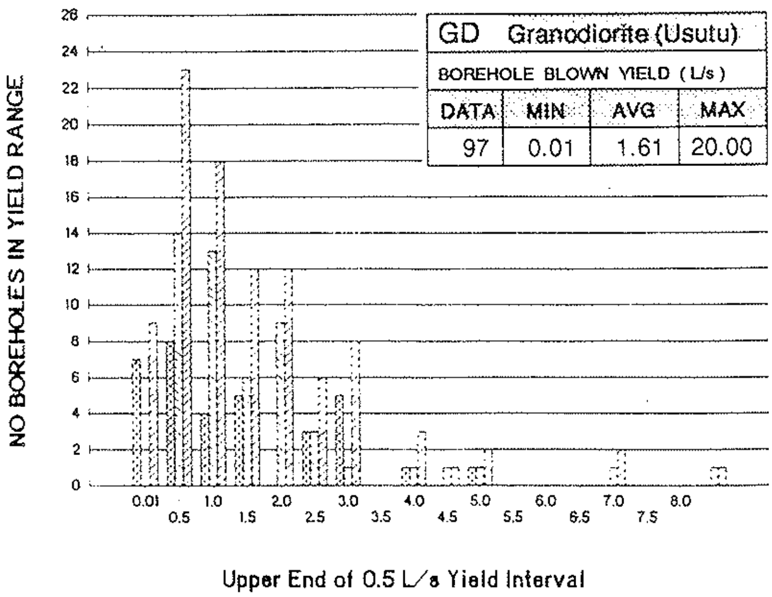


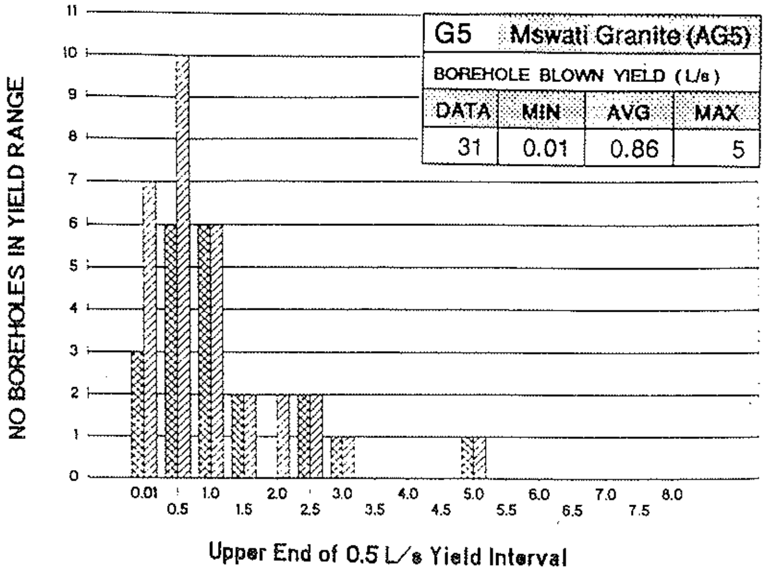
BOREHOLE YIELDS VS ELEVATIONS

FIGURE: 3


GR Other Granites
BOREHOLE BLOWN YIELD (L/s)
DATA 30 | MIN 0.01 | AVG 1.42 | MAX 5.0
NO BOREHOLES IN YIELD RANGE
0.01 0.5 1.0 1.5 2.0 2.5 3.0 3.5 4.0 4.5 5.0 5.5 6.0 6.5 7.0 7.5 8.0
Upper End of 0.5 L/s Yield Interval


G3 Lochiel Granite (AG3)
BOREHOLE BLOWN YIELDS (L/s)
DATA 80 | MIN 0.01 | AVG 1.17 | MAX 7.0
NO BOREHOLES IN YIELD RANGE
0.01 0.5 1.0 1.5 2.0 2.5 3.0 3.5 4.0 4.5 5.0 5.5 6.0 6.5 7.0 7.5 8.0
Upper End of 0.5 L/s Yield Interval


GD Granodiorite (Usutu)
BOREHOLE BLOWN YIELD (L/s)
DATA 97 | MIN 0.01 | AVG 1.61 | MAX 20.00
NO BOREHOLES IN YIELD RANGE
0.01 0.5 1.0 1.5 2.0 2.5 3.0 3.5 4.0 4.5 5.0 5.5 6.0 6.5 7.0 7.5 8.0
Upper End of 0.5 L/s Yield Interval

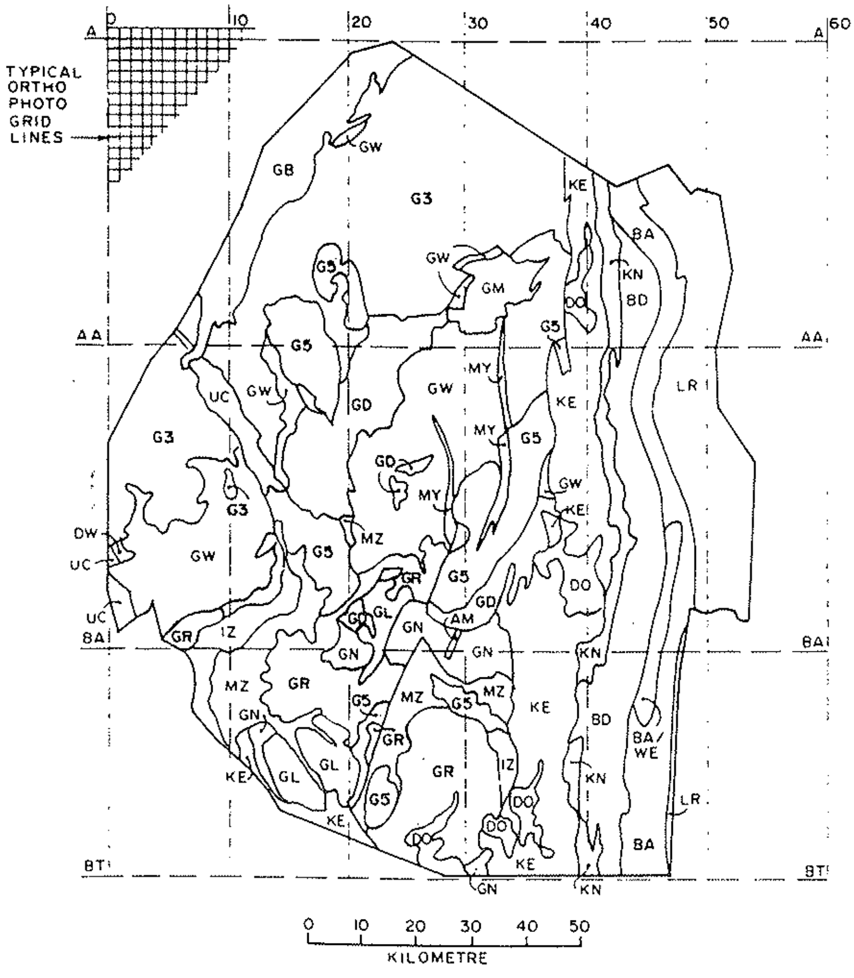


LEGEND

- All types
- Dolerite Contacts
- Undifferentiated

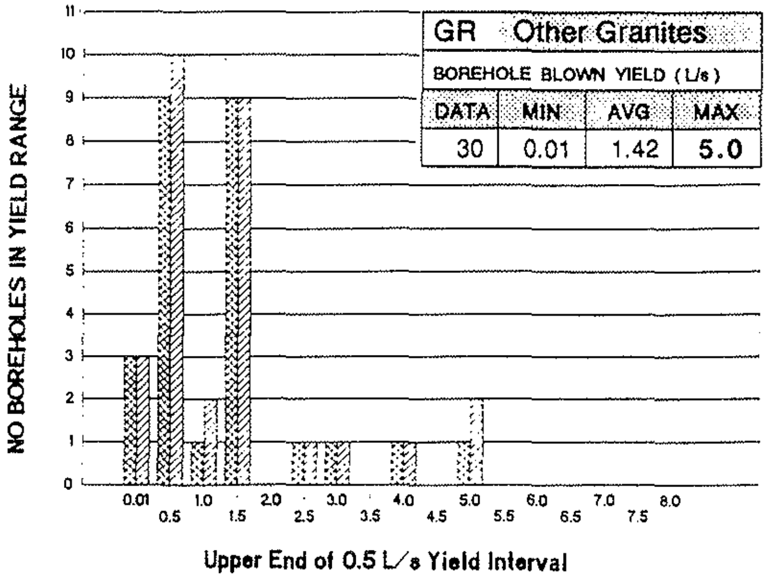
NOTES:

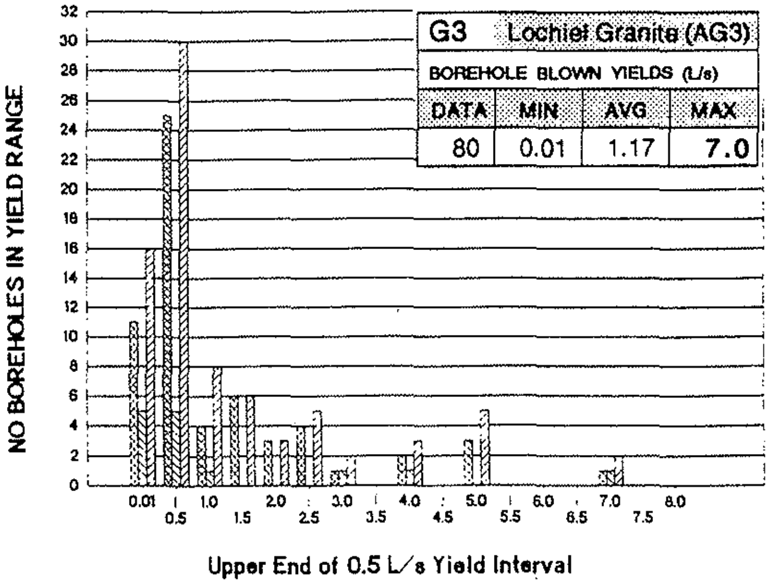
1) Only hydrogeological units with more than six sets of data are represented in the graphs.
2) For more information on the units, see data on Tables II, III and IV.
3) Blown yields indicated above were estimated at the time of of drilling and may not reflect true sustainable yields.

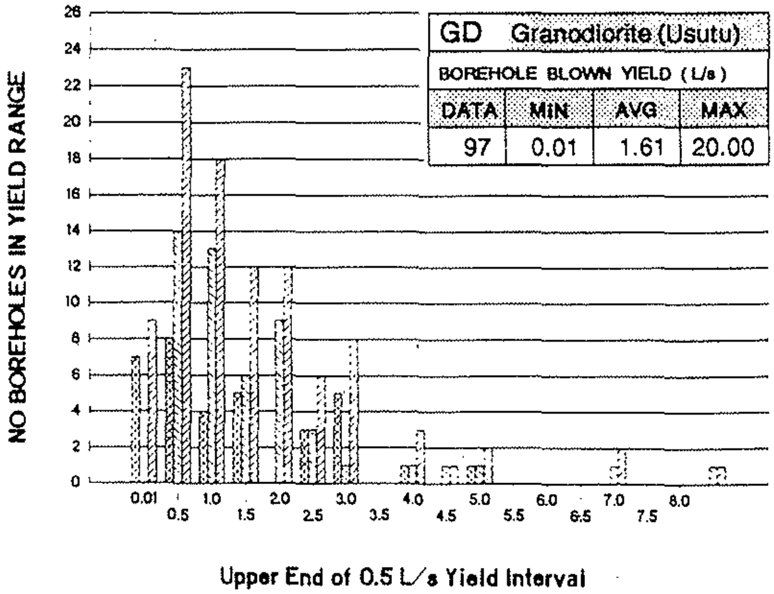


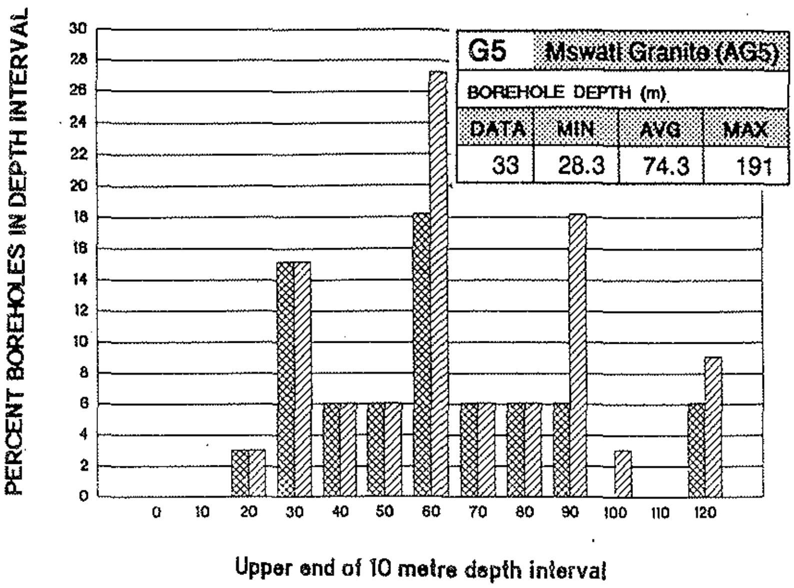
SIMPLIFIED HYDROGEOLOGIC MAP

BLOWN YIELDS : GRANITIC UNITS | FIGURE: 32


GR Other Granites
BOREHOLE BLOWN YIELD (L/s)
DATA MIN AVG MAX
30 0.01 1.42 5.0
NO BOREHOLES IN YIELD RANGE
0.01 0.5 1.0 1.5 2.0 2.5 3.0 3.5 4.0 4.5 5.0 5.5 6.0 6.5 7.0 7.5 8.0
Upper End of 0.5 L/s Yield Interval


G3 Lochiel Granite (AG3)
BOREHOLE BLOWN YIELDS (L/s)
DATA MIN AVG MAX
80 0.01 1.17 7.0
NO BOREHOLES IN YIELD RANGE
0.01 0.5 1.0 1.5 2.0 2.5 3.0 3.5 4.0 4.5 5.0 5.5 6.0 6.5 7.0 7.5 8.0
Upper End of 0.5 L/s Yield Interval


GD Granodiorite (Usutu)
BOREHOLE BLOWN YIELD (L/s)
DATA MIN AVG MAX
97 0.01 1.61 20.00
NO BOREHOLES IN YIELD RANGE
0.01 0.5 1.0 1.5 2.0 2.5 3.0 3.5 4.0 4.5 5.0 5.5 6.0 6.5 7.0 7.5 8.0
Upper End of 0.5 L/s Yield Interval



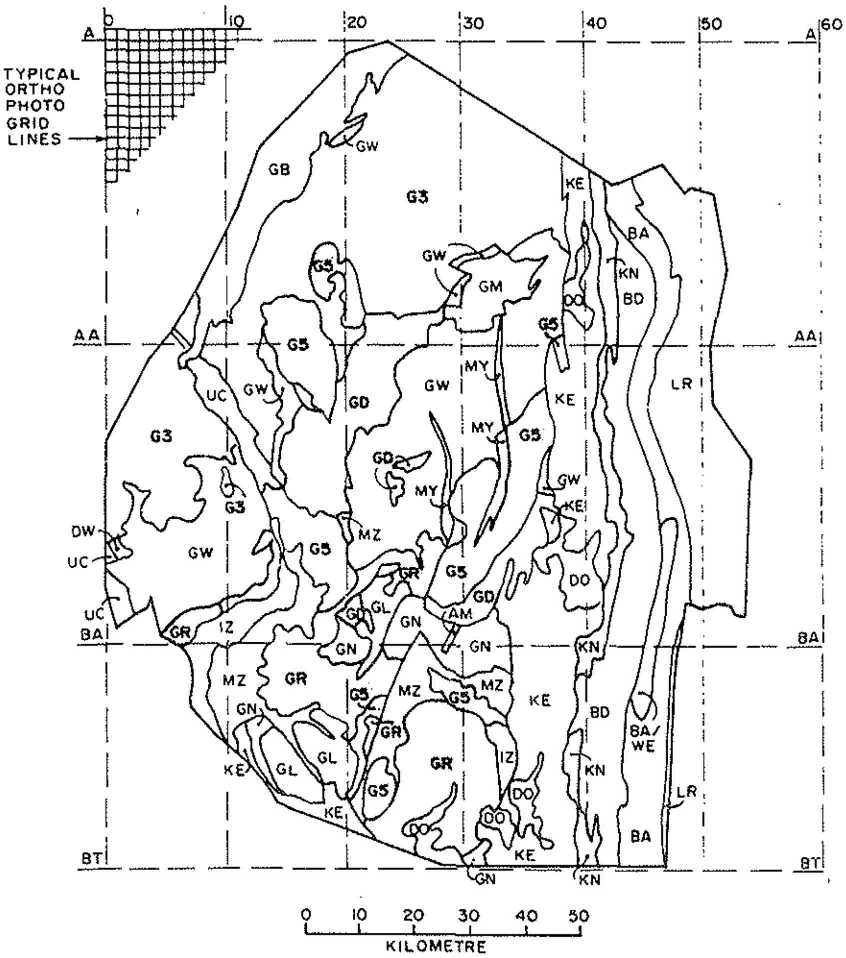
G5	Mswati Granite (AG5)		
BOREHOLE DEPTH (m)			
DATA	MIN	AVG	MAX
33	28.3	74.3	191

LEGEND

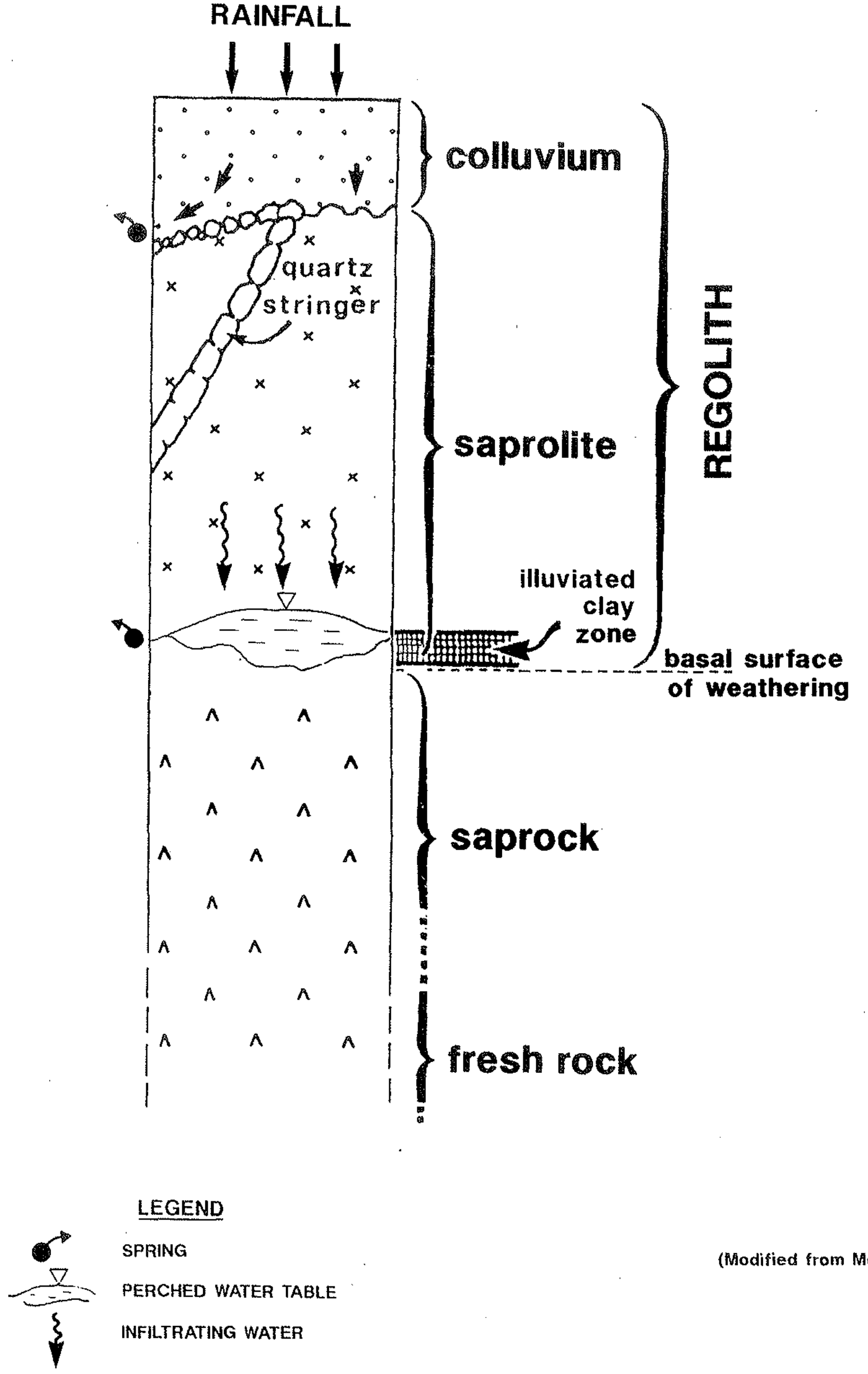
- All types
- Weathered
- Undifferentiated

NOTES:

1) Only hydrogeological units with more than six sets of data are represented in the graphs.
2) For more information on the units, see data on Tables II, III and IV.



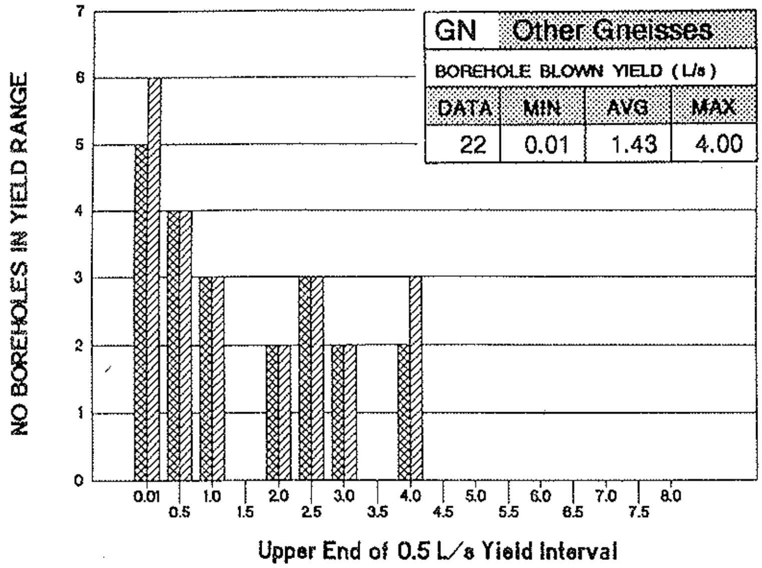
SIMPLIFIED HYDROGEOLOGIC MAP

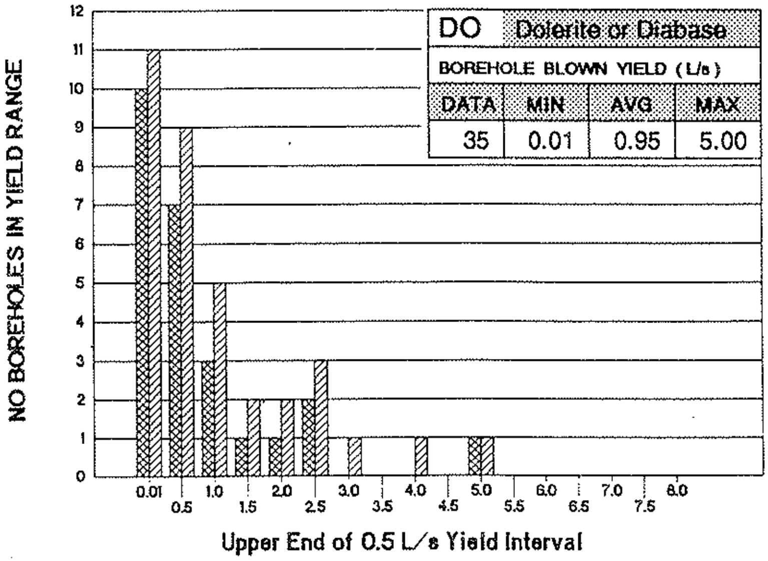


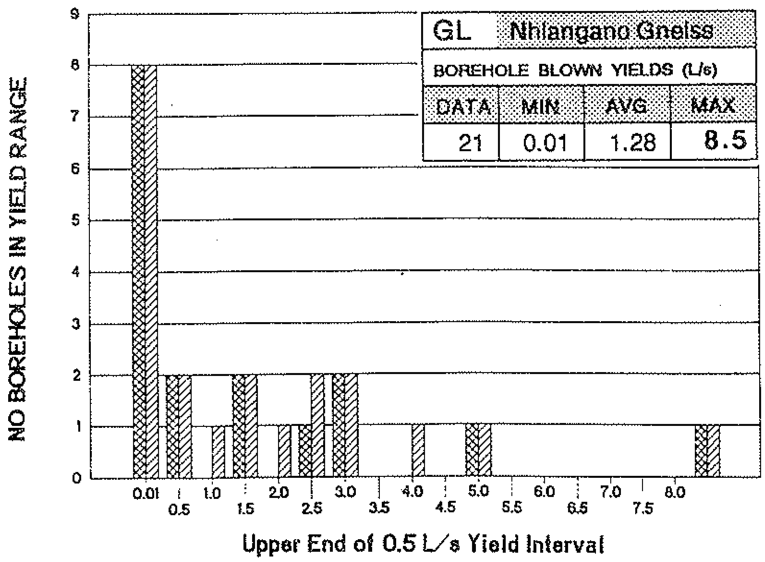
(Modified from McFarlane, 1987)

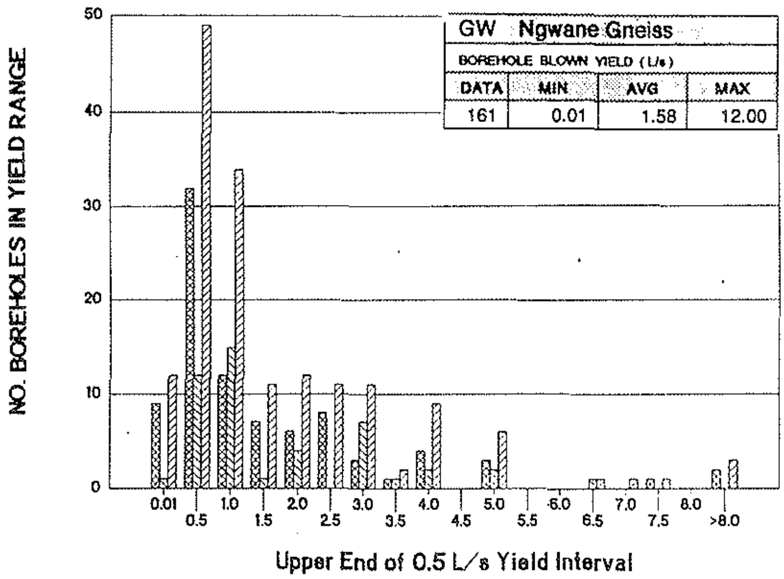
SCHEMATIC SHOWING TYPICAL WEATHERING PROFILES IN GRANITIC AREAS

FIGURE: 34


GN Other Gneisses
BOREHOLE BLOWN YIELD (L/s)
DATA MIN AVG MAX
22 0.01 1.43 4.00
NO BOREHOLES IN YIELD RANGE
Upper End of 0.5 L/s Yield Interval


DO Dolerite or Diabase
BOREHOLE BLOWN YIELD (L/s)
DATA MIN AVG MAX
35 0.01 0.95 5.00
NO BOREHOLES IN YIELD RANGE
Upper End of 0.5 L/s Yield Interval


GL Nhlangano Gneiss
BOREHOLE BLOWN YIELDS (L/s)
DATA MIN AVG MAX
21 0.01 1.28 8.5
NO BOREHOLES IN YIELD RANGE
Upper End of 0.5 L/s Yield Interval

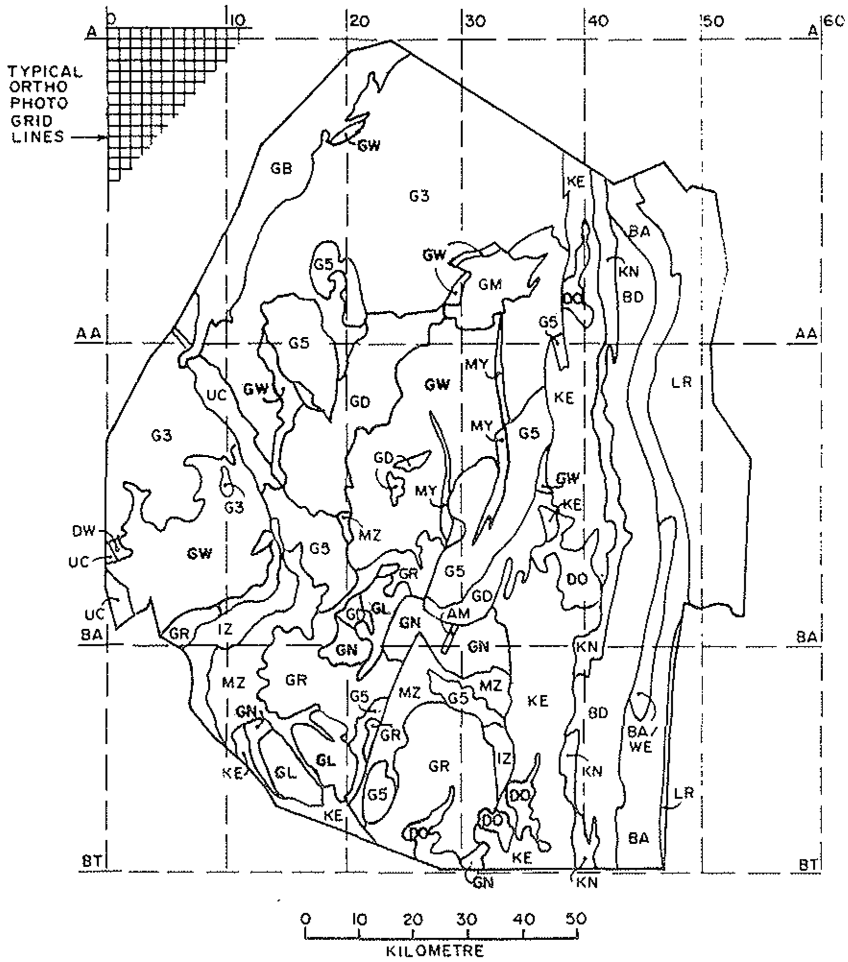


LEGEND

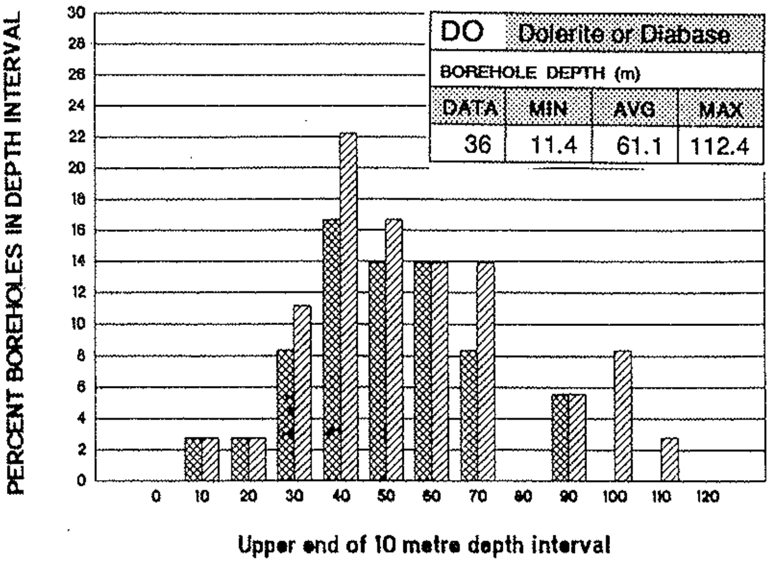
- All types
- Weathered
- Undifferentiated

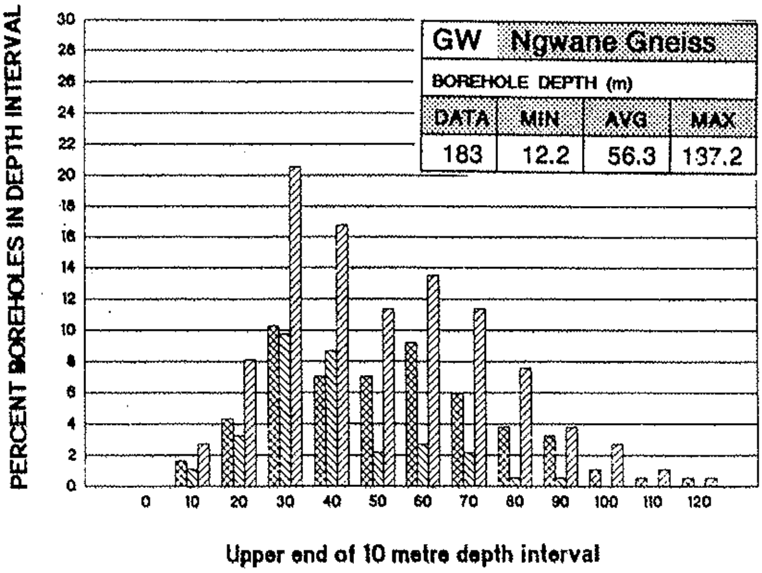
NOTES:

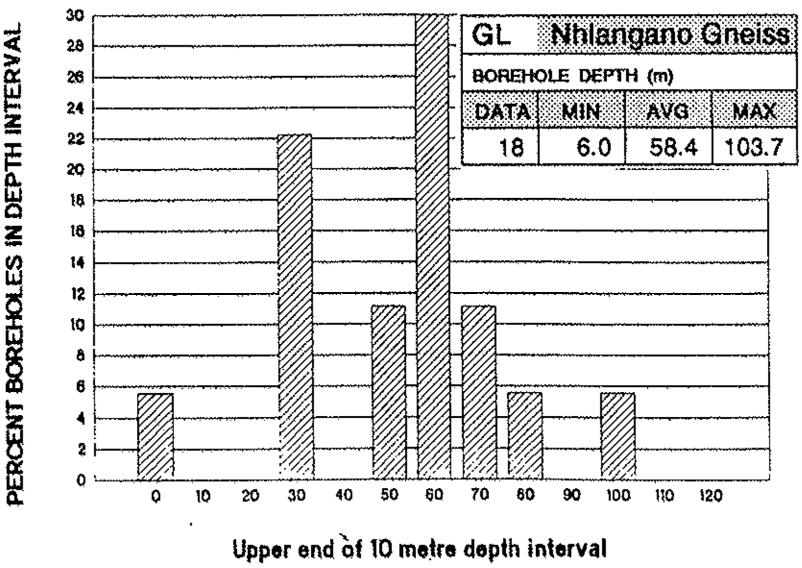
1) Only hydrogeological units with more than six sets of data are represented in the graphs.
2) For more information on the units, see data on Tables II, III and IV.
3) Blown yields indicated above were estimated at the time of of drilling and may not reflect true sustainable yields.

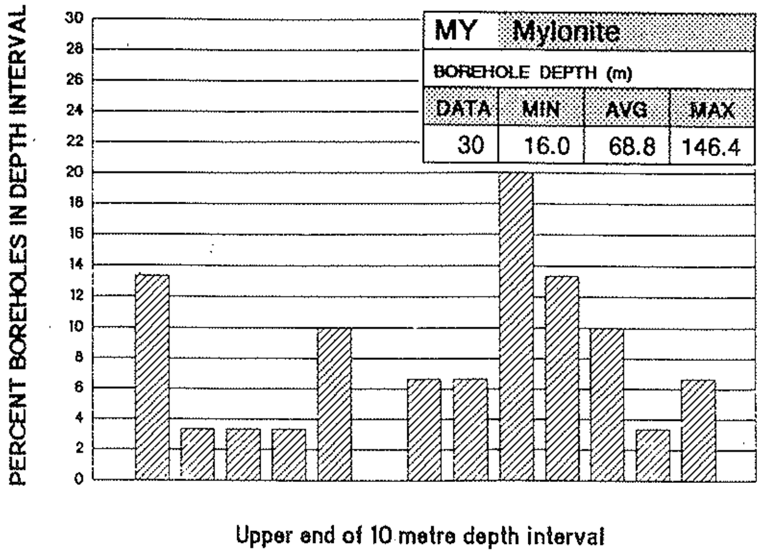


SIMPLIFIED HYDROGEOLOGIC MAP


DO Dolerite or Diabase
BOREHOLE DEPTH (m)
DATA MIN AVG MAX
36 11.4 61.1 112.4
PERCENT BOREHOLES IN DEPTH INTERVAL
Upper end of 10 metre depth interval


GW Ngwane Gneiss
BOREHOLE DEPTH (m)
DATA MIN AVG MAX
183 12.2 56.3 137.2
PERCENT BOREHOLES IN DEPTH INTERVAL
Upper end of 10 metre depth interval


GL Nhlangano Gneiss
BOREHOLE DEPTH (m)
DATA MIN AVG MAX
18 6.0 58.4 103.7
PERCENT BOREHOLES IN DEPTH INTERVAL
Upper end of 10 metre depth interval



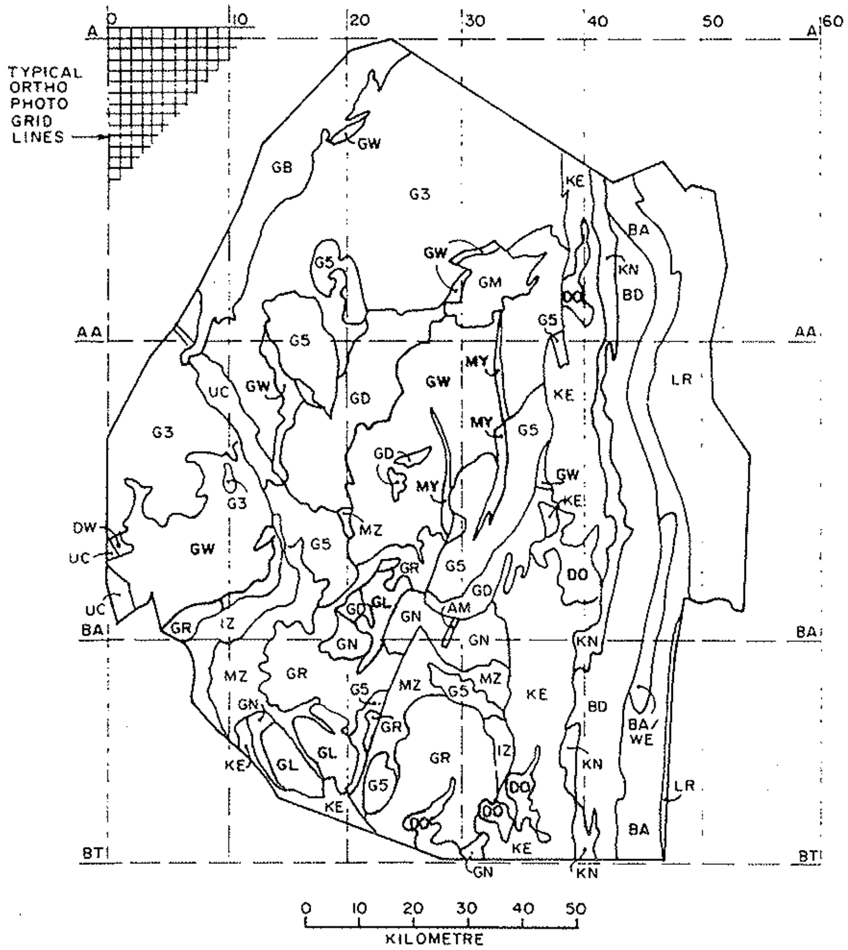
MY	Mylonite		
BOREHOLE DEPTH (m)			
DATA	MIN	AVG	MAX
30	16.0	68.8	146.4

LEGEND

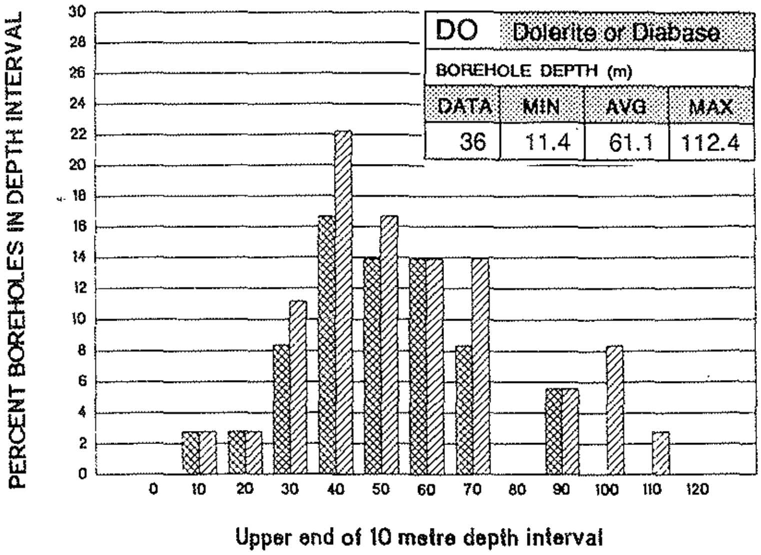
- All types
- Weathered
- Undifferentiated

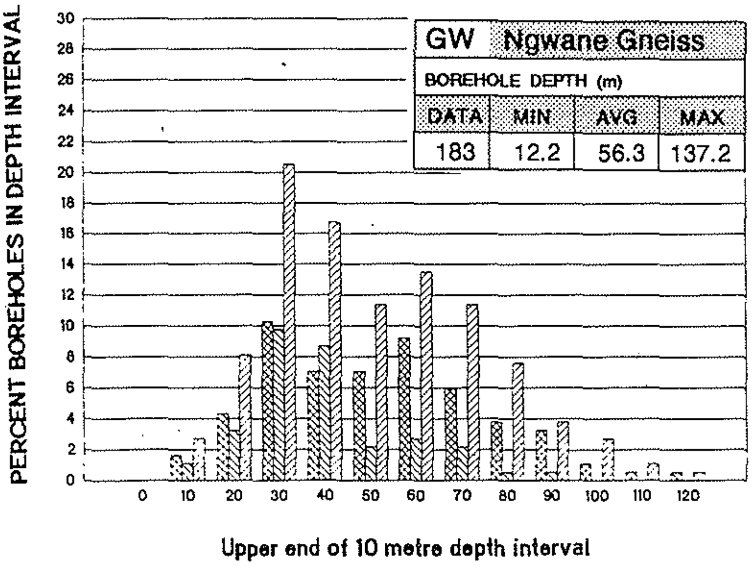
NOTES:

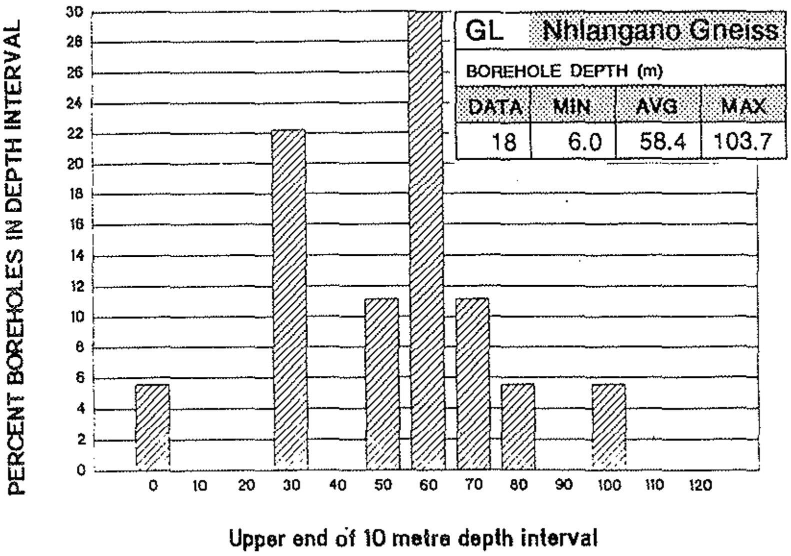
1) Only hydrogeological units with more than six sets of data are represented in the graphs.
2) For more information on the units, see data on Tables II, III and IV.

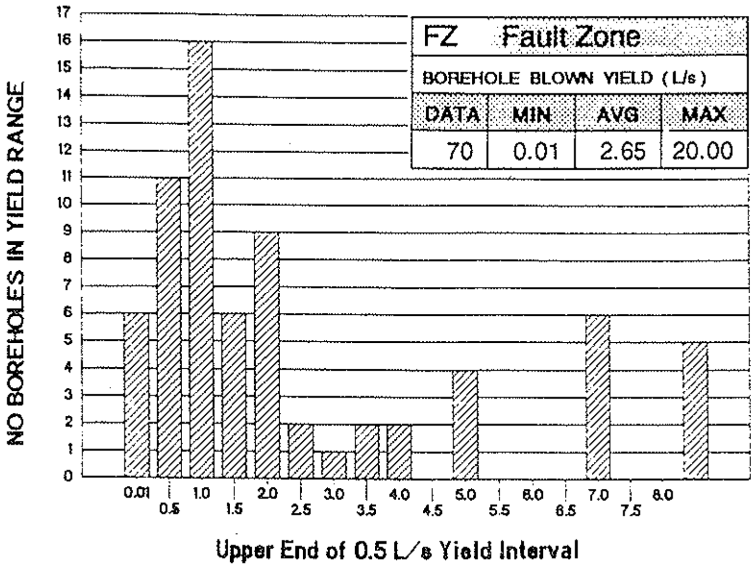


SIMPLIFIED HYDROGEOLOGIC MAP


DO Dolerite or Diabase
BOREHOLE DEPTH (m)
DATA MIN AVG MAX
36 11.4 61.1 112.4
PERCENT BOREHOLES IN DEPTH INTERVAL
Upper end of 10 metre depth interval


GW Ngwane Gneiss
BOREHOLE DEPTH (m)
DATA MIN AVG MAX
183 12.2 56.3 137.2
PERCENT BOREHOLES IN DEPTH INTERVAL
Upper end of 10 metre depth interval


GL Nhlangano Gneiss
BOREHOLE DEPTH (m)
DATA MIN AVG MAX
18 6.0 58.4 103.7
PERCENT BOREHOLES IN DEPTH INTERVAL
Upper end of 10 metre depth interval

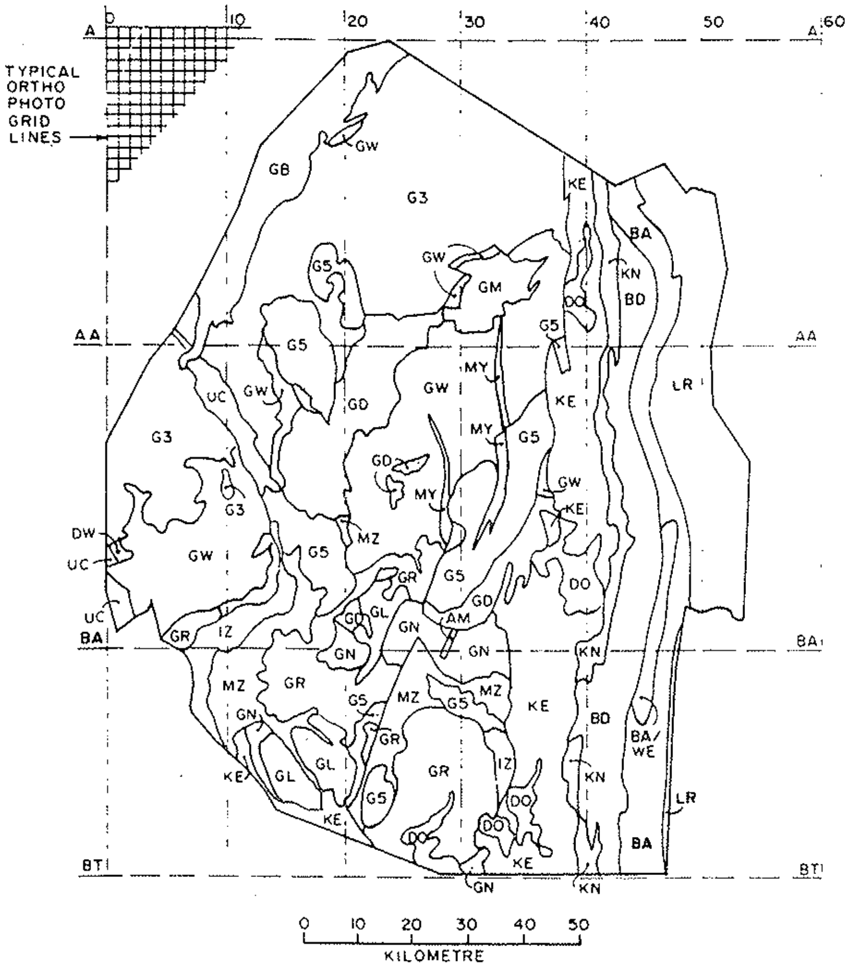


LEGEND

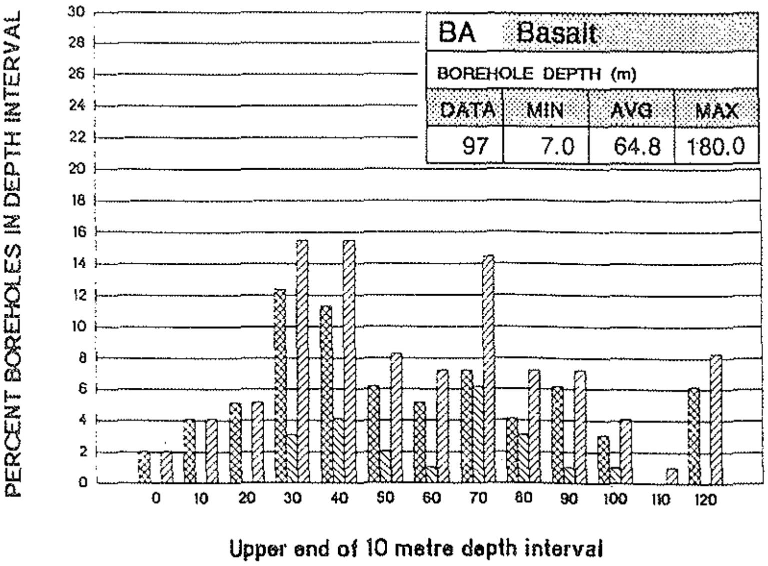
- All types
- Weathered
- Undifferentiated

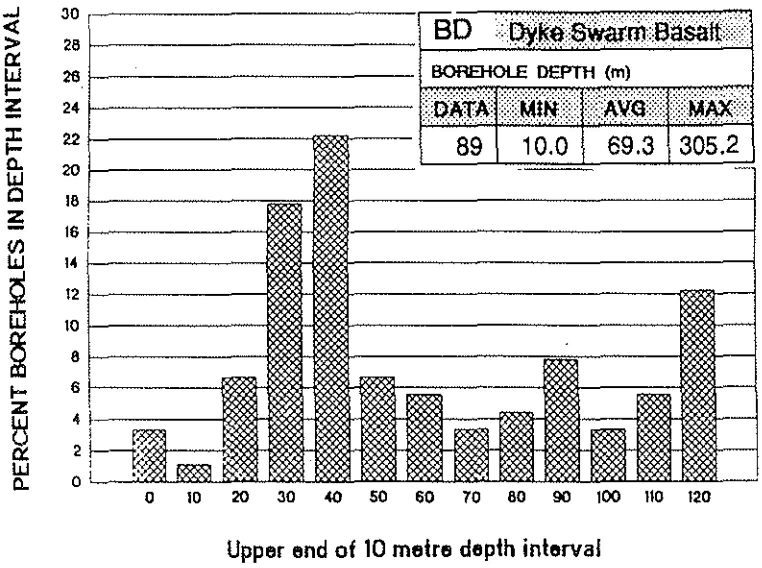
NOTES:

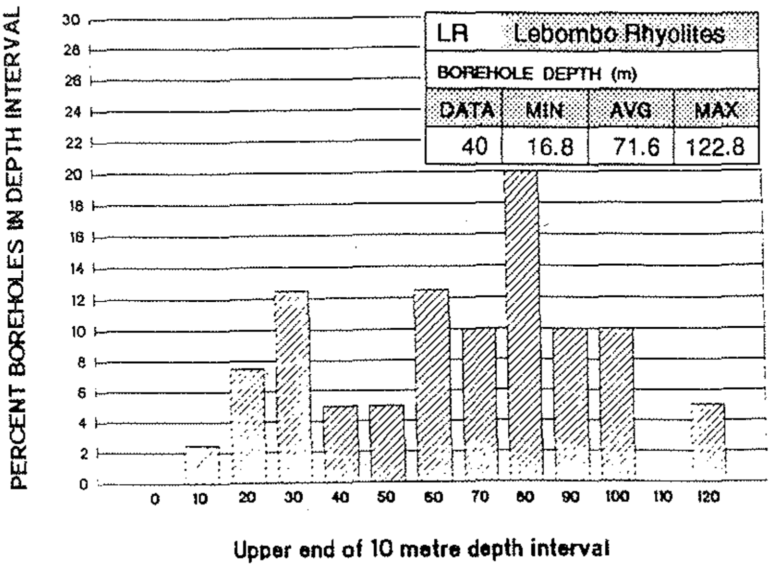
1) Only hydrogeological units with more than six sets of data are represented in the graphs.
2) For more information on the units, see data on Tables II, III and IV.
3) Blown yields indicated above were estimated at the time of of drilling and may not reflect true sustainable yields.

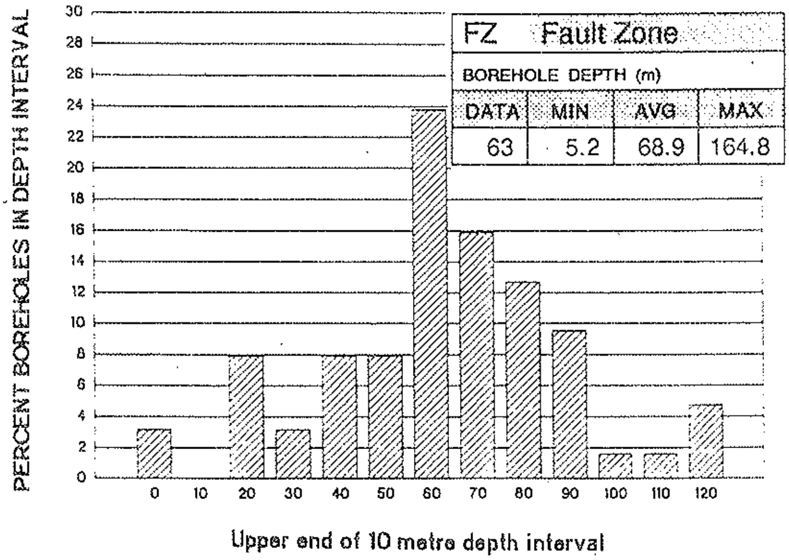


SIMPLIFIED HYDROGEOLOGIC MAP


BA Basalt
BOREHOLE DEPTH (m)
DATA MIN AVG MAX
97 7.0 64.8 180.0
PERCENT BOREHOLES IN DEPTH INTERVAL
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
0 10 20 30 40 50 60 70 80 90 100 110 120
Upper end of 10 metre depth interval


BD Dyke Swarm Basalt
BOREHOLE DEPTH (m)
DATA MIN AVG MAX
89 10.0 69.3 305.2
PERCENT BOREHOLES IN DEPTH INTERVAL
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
0 10 20 30 40 50 60 70 80 90 100 110 120
Upper end of 10 metre depth interval


LR Lebombo Rhyolites
BOREHOLE DEPTH (m)
DATA MIN AVG MAX
40 16.8 71.6 122.8
PERCENT BOREHOLES IN DEPTH INTERVAL
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
0 10 20 30 40 50 60 70 80 90 100 110 120
Upper end of 10 metre depth interval



LEGEND

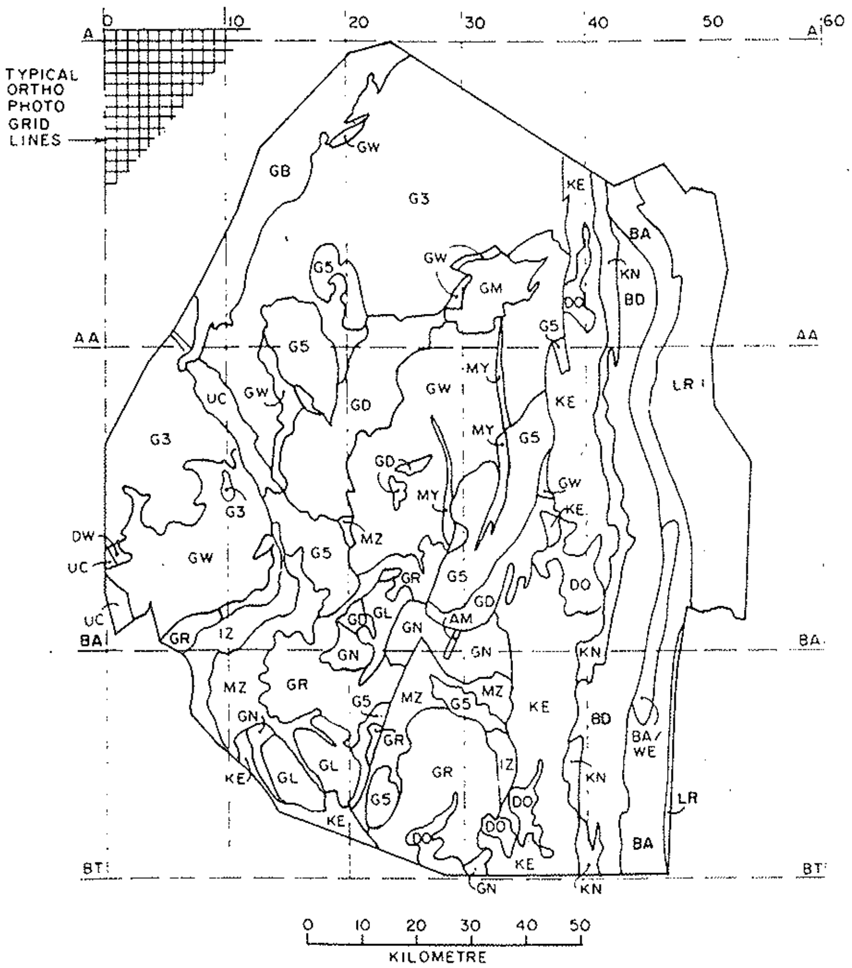
All types

Weathered

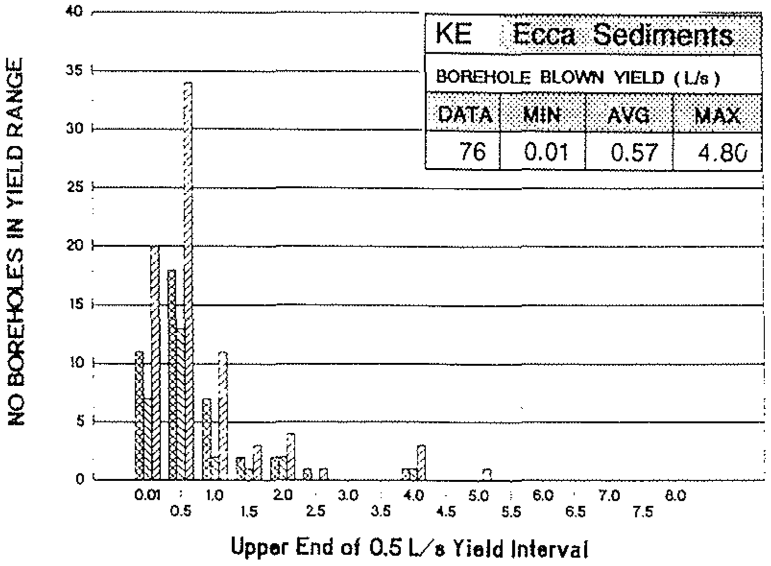
Undifferentiated

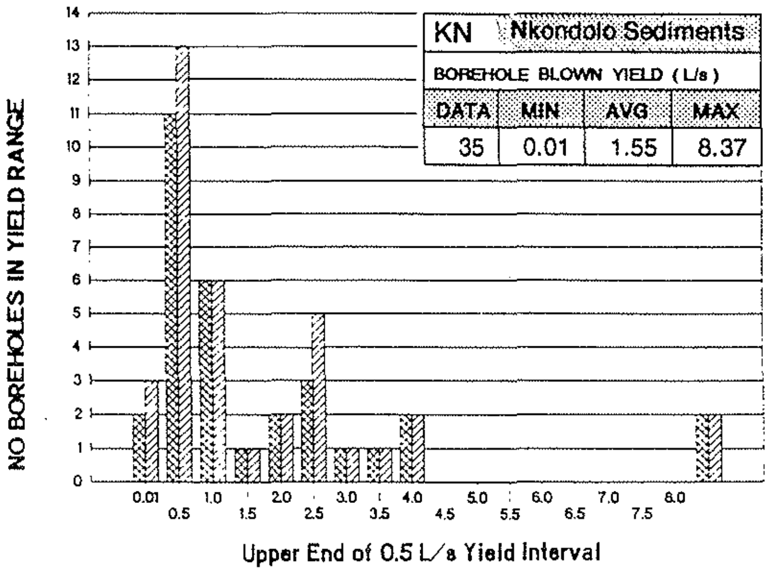
NOTES:

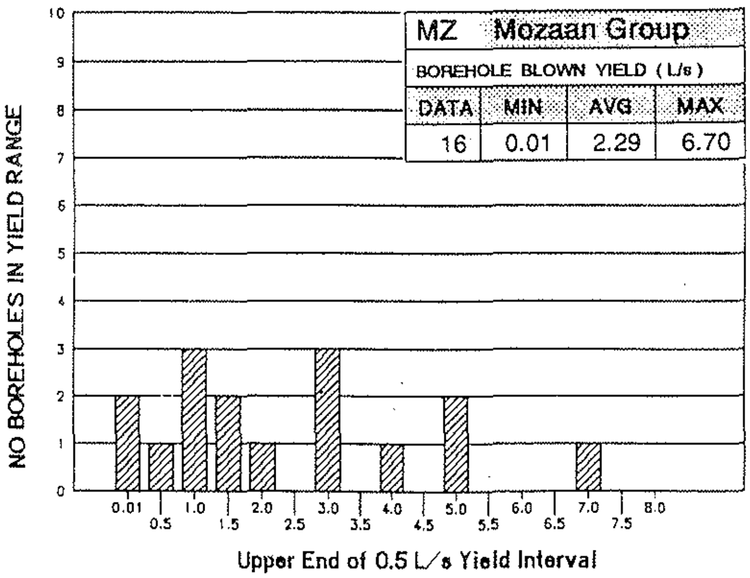
1) Only hydrogeological units with more than six sets of data are represented in the graphs.
2) For more information on the units, see data on Tables II, III and IV.

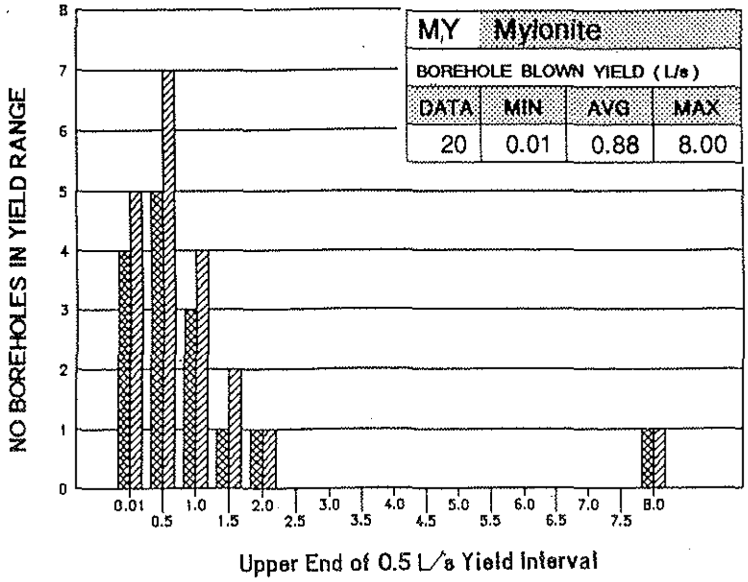


SIMPLIFIED HYDROGEOLOGIC MAP


KE Ecca Sediments
BOREHOLE BLOWN YIELD (L/s)
DATA MIN AVG MAX
76 0.01 0.57 4.80
NO BOREHOLES IN YIELD RANGE
Upper End of 0.5 L/s Yield Interval


KN Nkondolo Sediments
BOREHOLE BLOWN YIELD (L/s)
DATA MIN AVG MAX
35 0.01 1.55 8.37
NO BOREHOLES IN YIELD RANGE
Upper End of 0.5 L/s Yield Interval


MZ Mozaan Group
BOREHOLE BLOWN YIELD (L/s)
DATA MIN AVG MAX
16 0.01 2.29 6.70
NO BOREHOLES IN YIELD RANGE
Upper End of 0.5 L/s Yield Interval



LEGEND

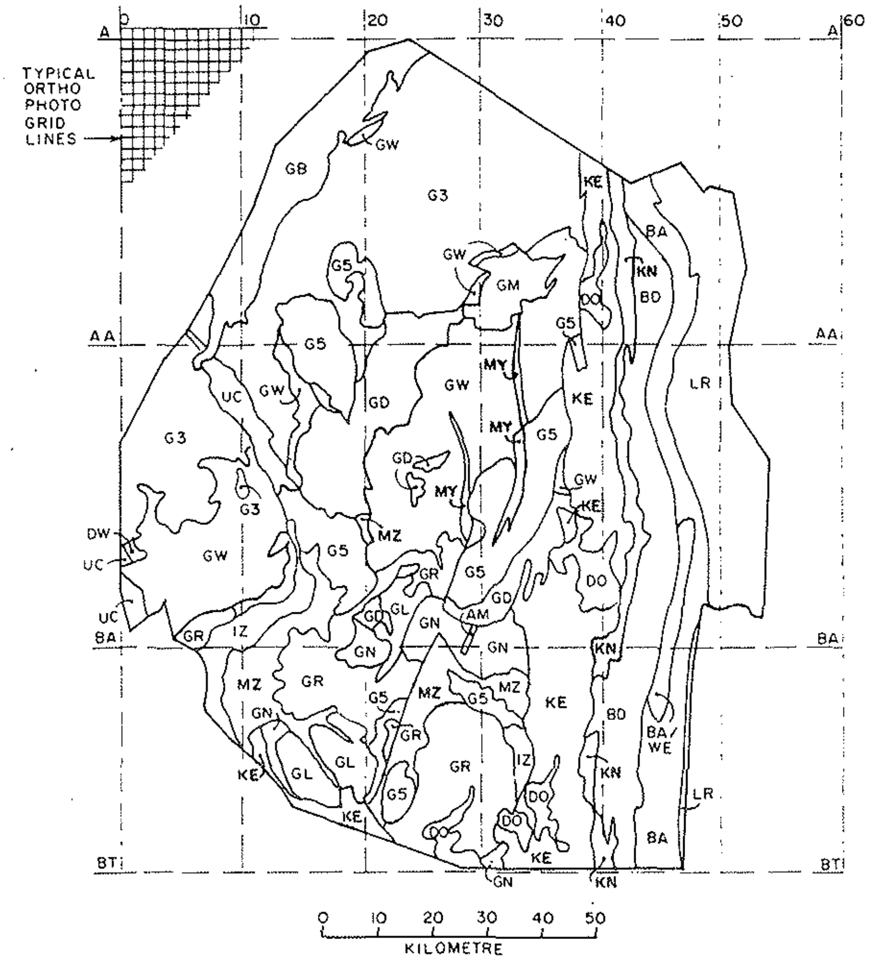
Undifferentiated

Dolerite Contacts

All types

NOTES:

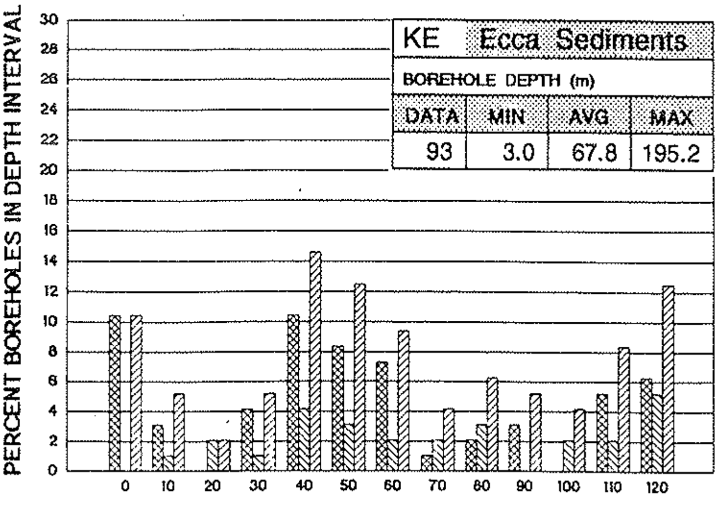
1) Only hydrogeological units with more than six sets of data are represented in the graphs.
2) For more information on the units, see data on Tables II, III and IV.
3) Blown yields indicated above were estimated at the time of of drilling and may not reflect true sustainable yields.



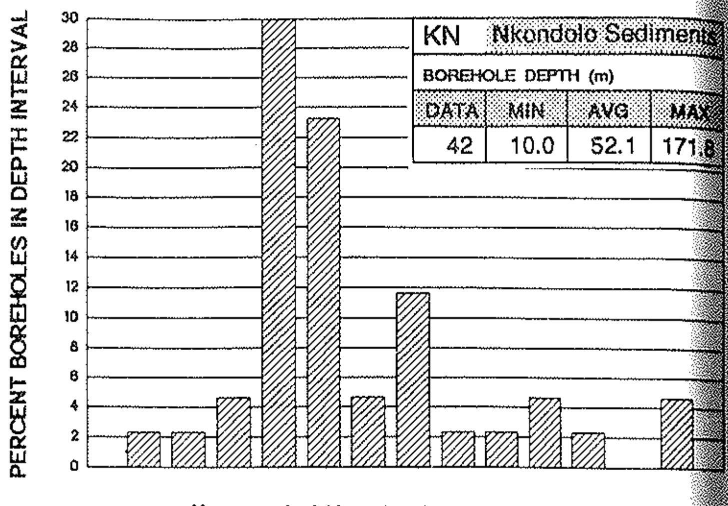
SIMPLIFIED HYDROGEOLOGIC MAP

BLOWN YIELDS: SEDIMENTARY AND MYLONITE UNITS

FIGURE: 39



Upper end of 10 metre depth interval



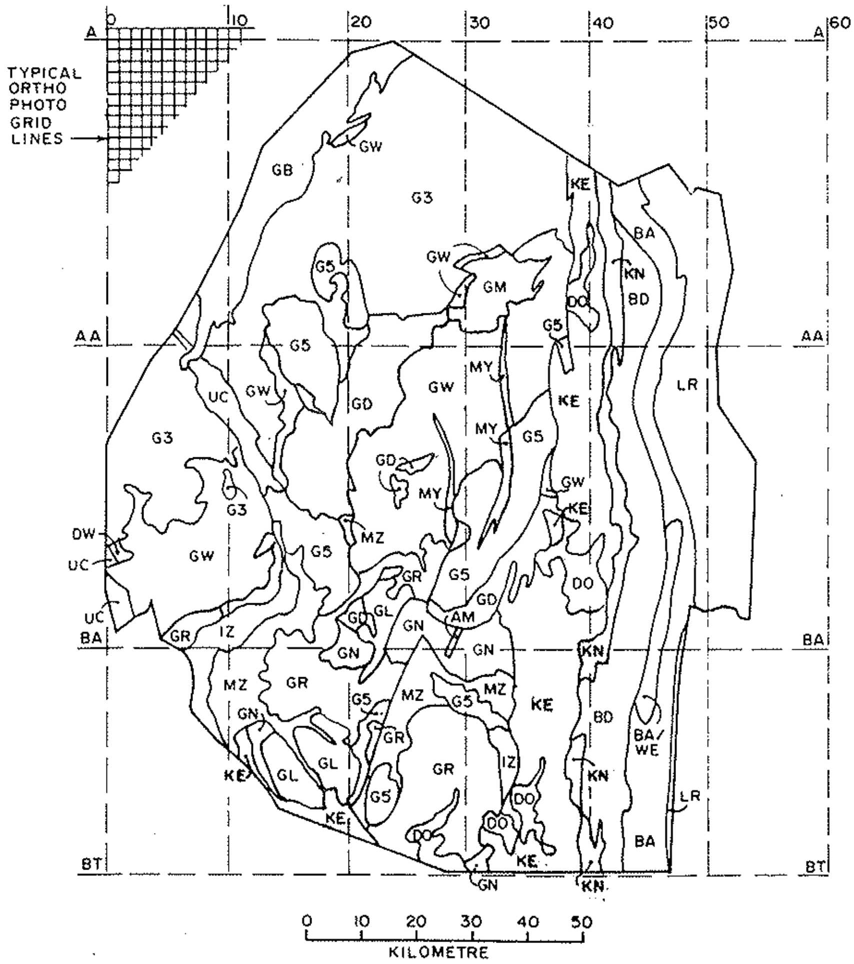
Upper end of 10 metre depth interval

NOTES:

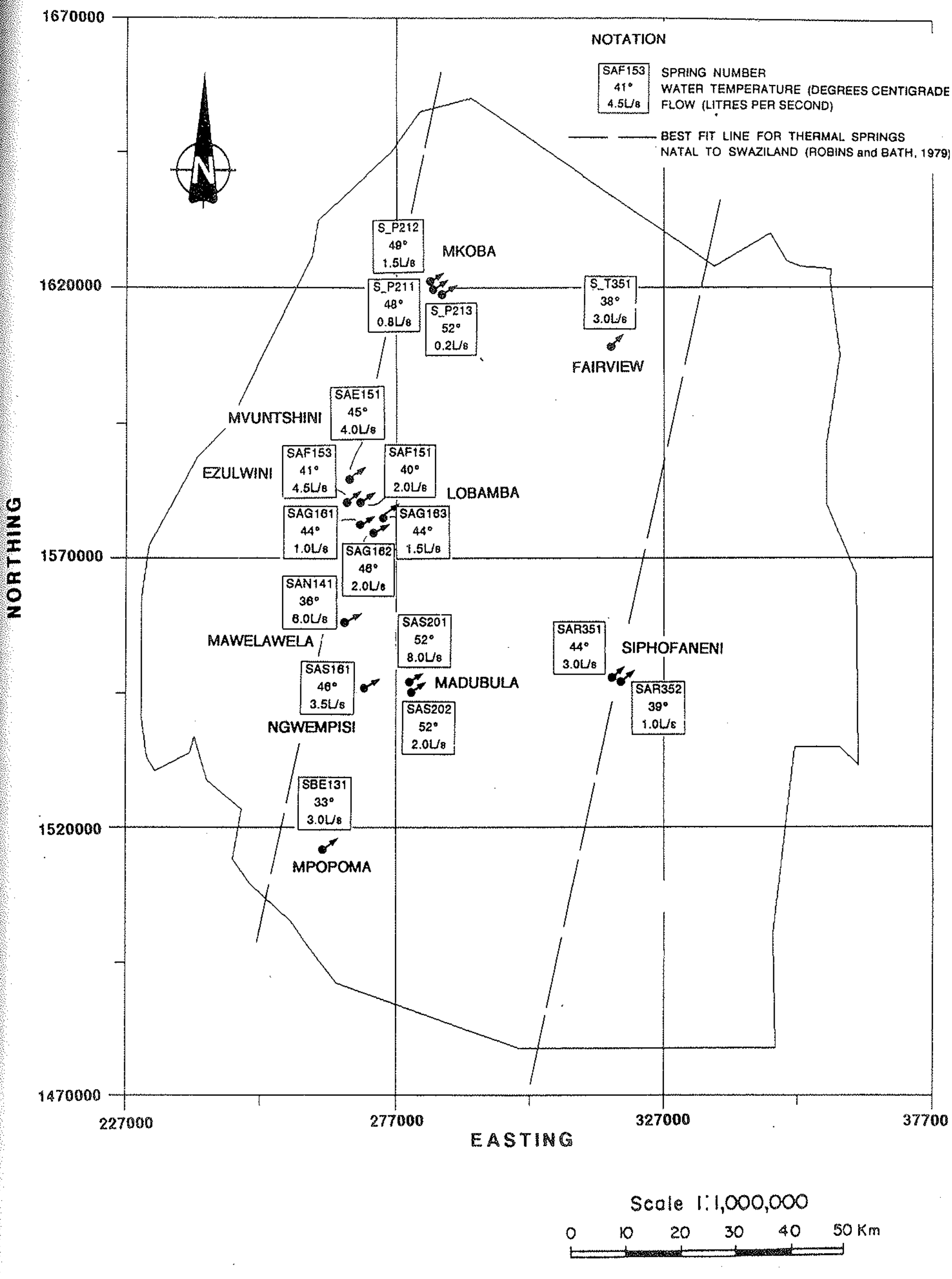
1) Only hydrogeological units with more than six sets of data are represented in the graphs.
2) For more information on the units, see data on Tables II, III and IV.

LEGEND

- All types
- Weathered
- Undifferentiated

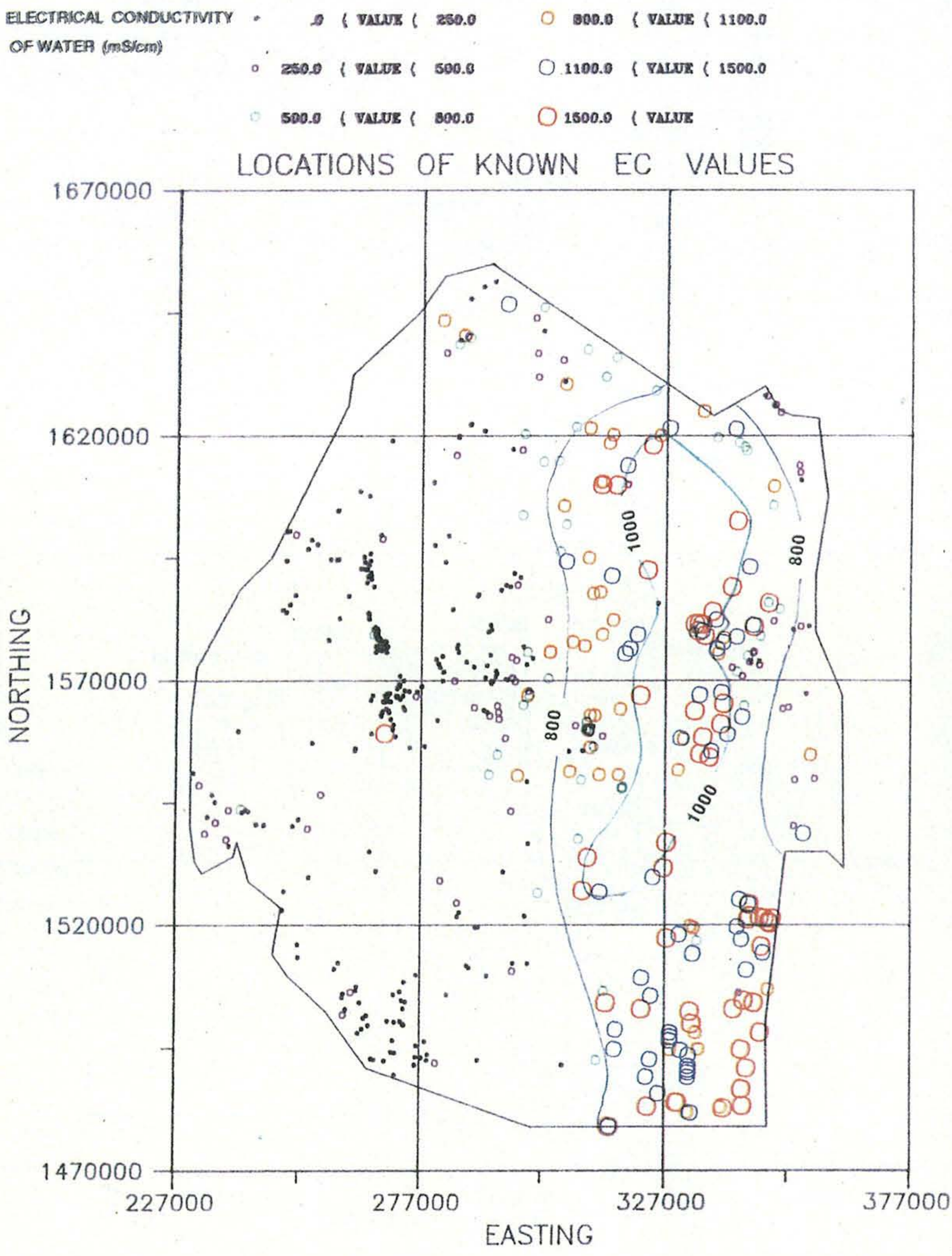


SIMPLIFIED HYDROGEOLOGIC MAP



LOCATION OF THERMAL SPRINGS

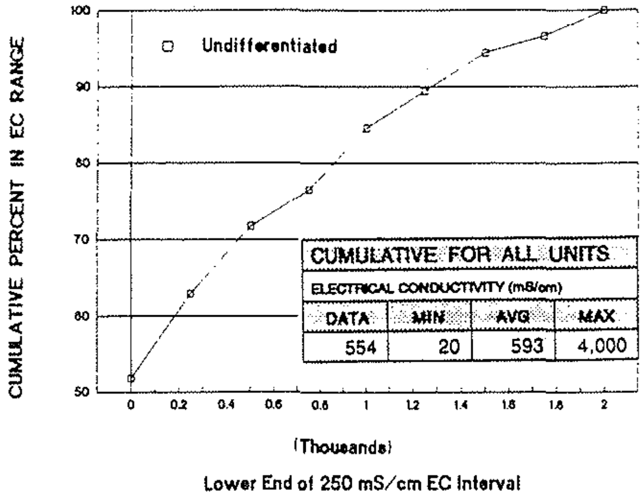
FIGURE: 41

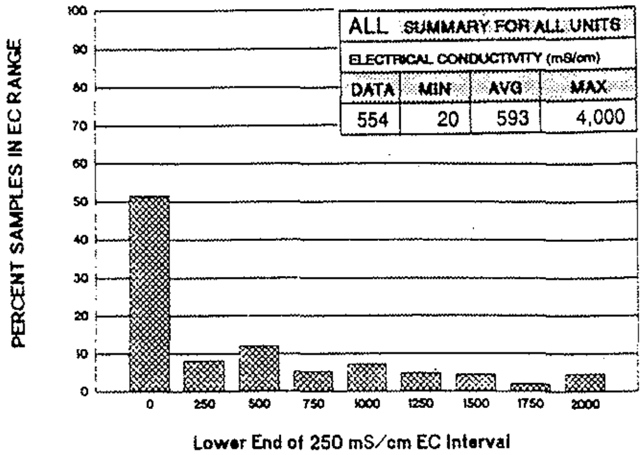


1000 - DOMINANT EC VALUES (mS/cm)

ELECTRICAL CONDUCTIVITY OF GROUNDWATERS

FIGURE: 4



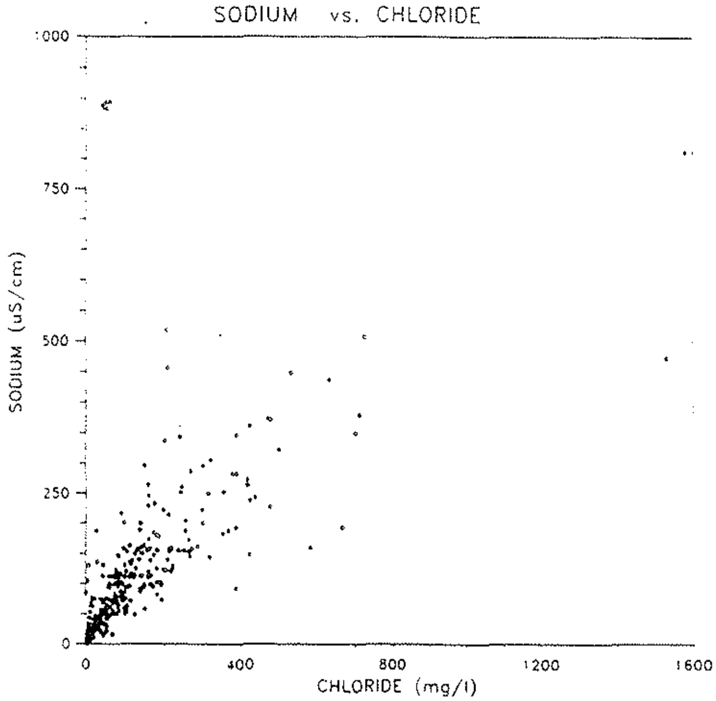


NOTES:

1) Only hydrogeological units with more than six sets of data are represented in the graphs.
2) For more information on the units, see data on Tables III and IV.
3) Data sets include springs

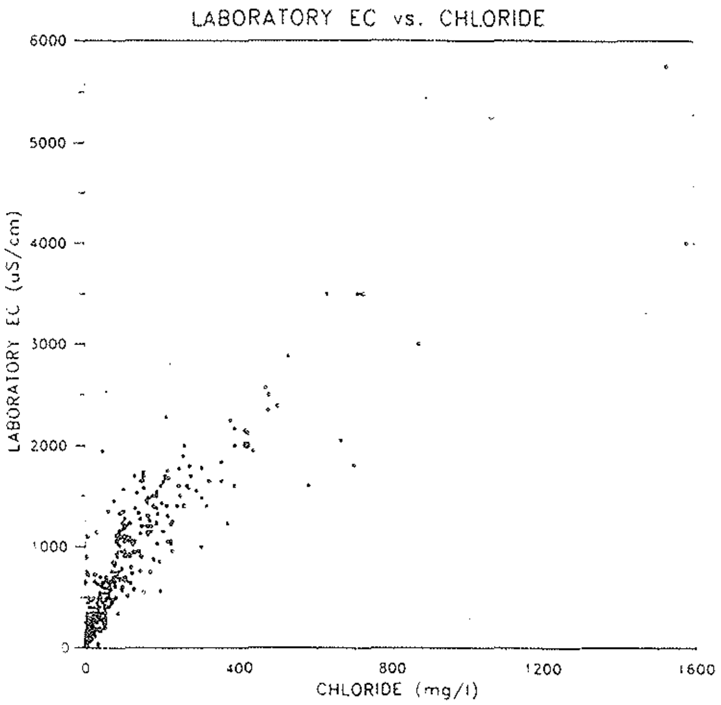
ELECTRICAL CONDUCTIVITY OF WATER : SUMMARY

FIGURE: 43



SODIUM vs. CHLORIDE

		Cl	Na
Mean	:	77.97	68.46
Variance	:	21526	8502.67
Standard Deviation	:	146.72	92.21
Coef. of variation	:	188.2	134.7
Minimum	:	1.00	1.00
Maximum	:	1580.00	812.00
1st quartile	:	5.00	11.00
Median	:	16.00	26.00
3rd quartile	:	94.50	26.00
Sample size	:	554	
Covariance	:	11626	
Correlation (Pearson)	:	0.859	
Correlation (Spearman)	:	0.895	

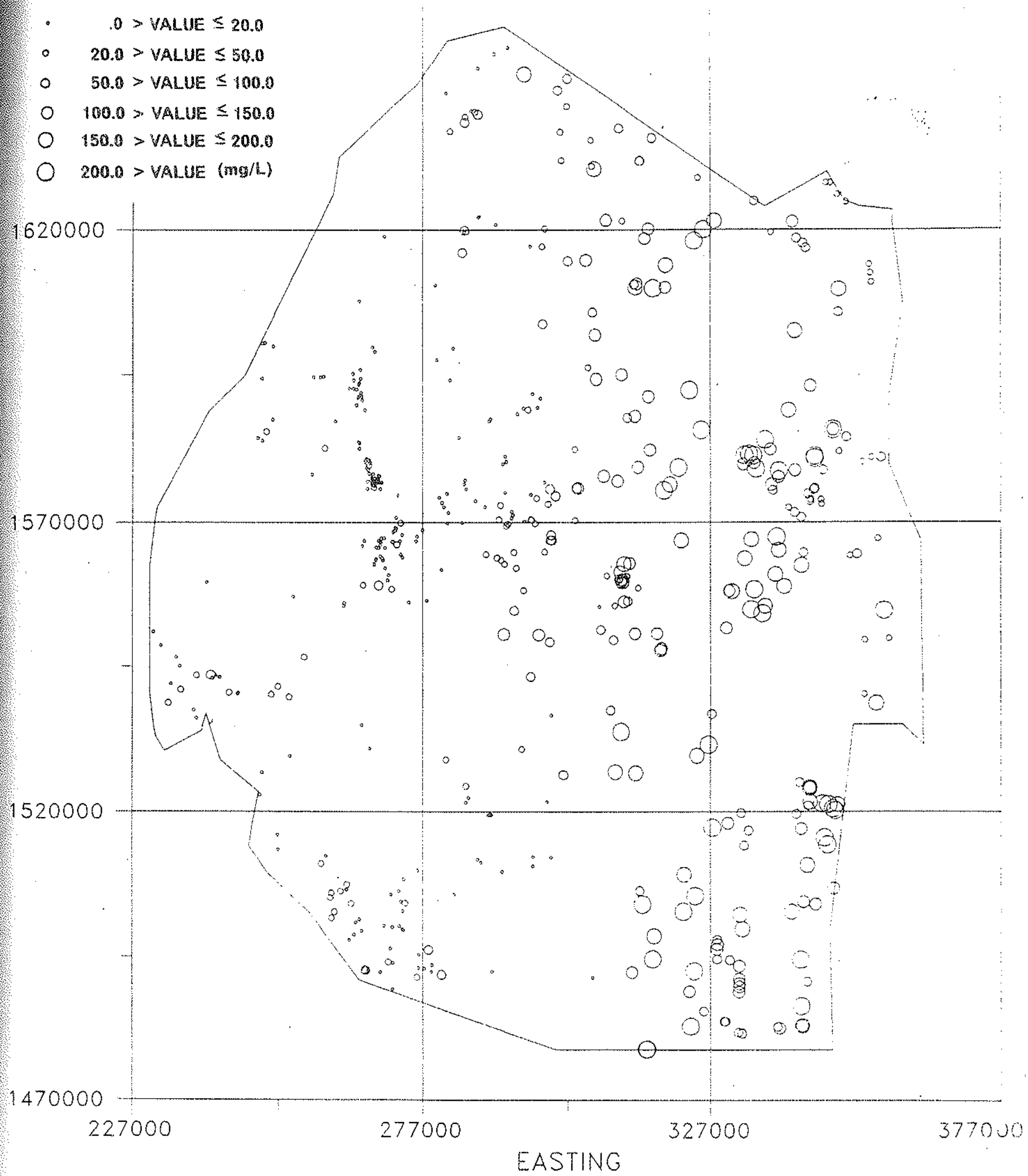


LAB EC VS. CHLORIDE

		Cl	LAB EC
Mean	:	79.28	580.53
Variance	:	22665	486190
Standard Deviation	:	150.55	697.27
Coef. of variation	:	189.9	120.1
Minimum	:	1.00	10.00
Maximum	:	1580.00	5750.00
1st quartile	:	5.00	100.50
Median	:	14.00	240.00
3rd quartile	:	98.00	240.00
Sample size	:	494	
Covariance	:	94027	
Correlation (Pearson)	:	0.896	
Correlation (Spearman)	:	0.909	

RELATIONSHIP BETWEEN CHLORIDE; SODIUM AND ELECTRICAL CONDUCTIVITY IN GROUNDWATER

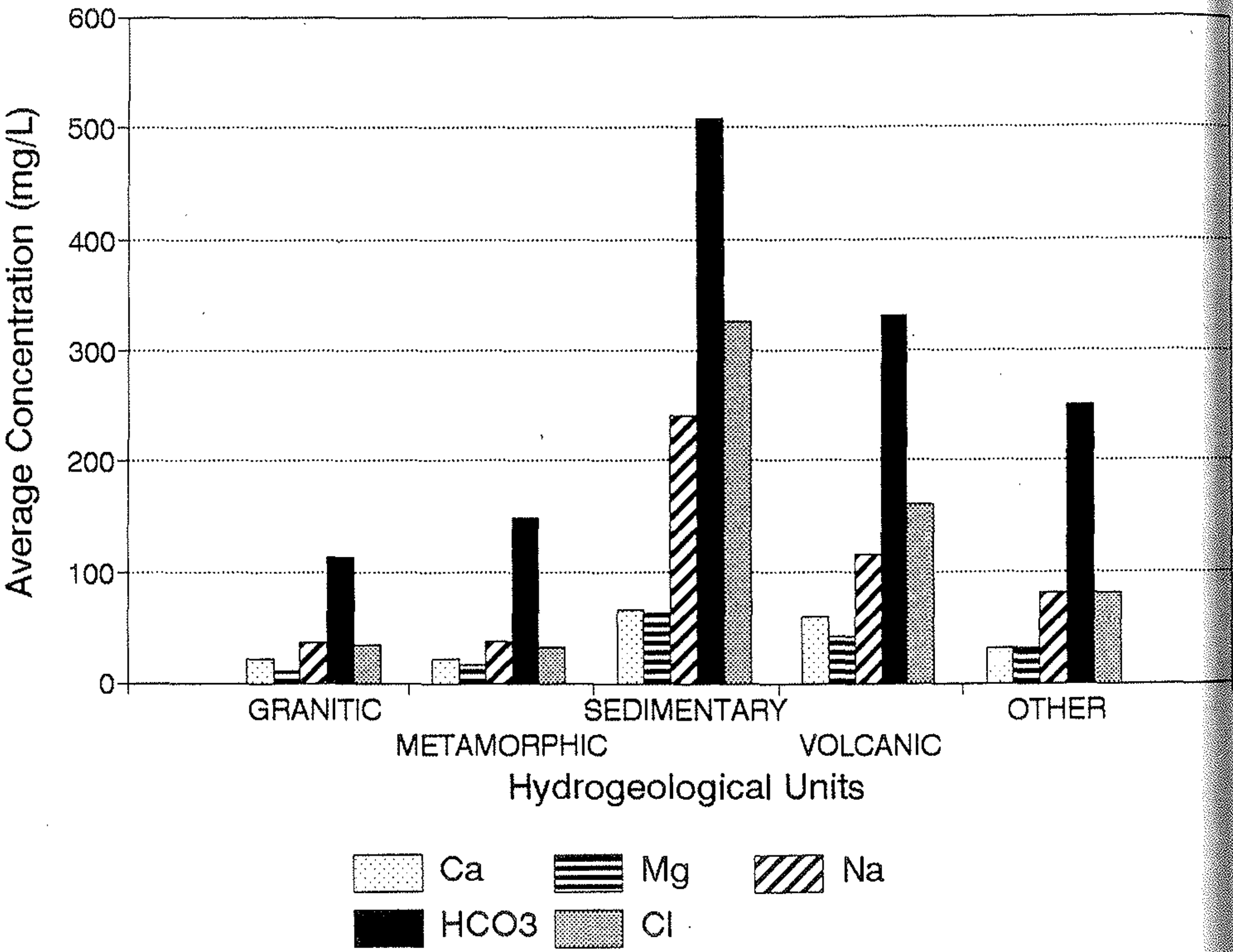
FIGURE: 4



NOTES:

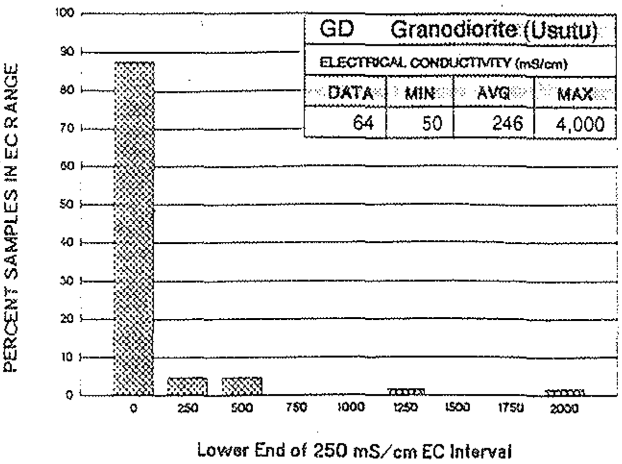
1) Values expresed in mg/L.
2) Data based on inorganic chemistry analyses from springs and boreholes, with ionic balances in the range 70 to 130% (expressed as equivalent anions/cations)

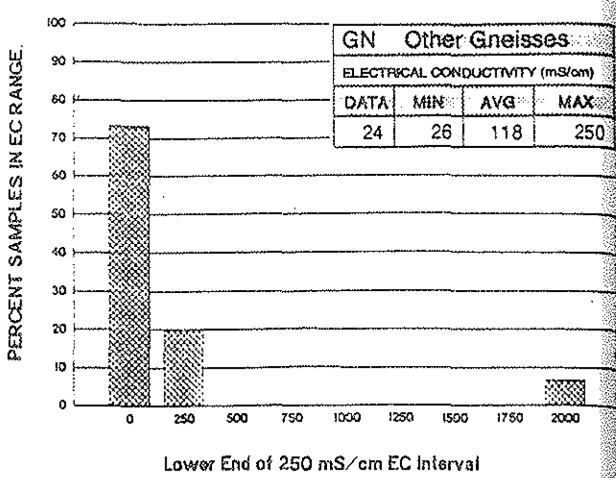
DISTRIBUTION OF SODIUM IN GROUNDWATERS | FIGURE: 45

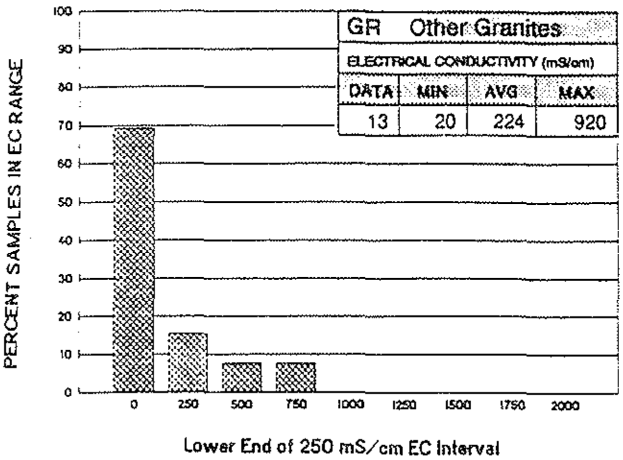


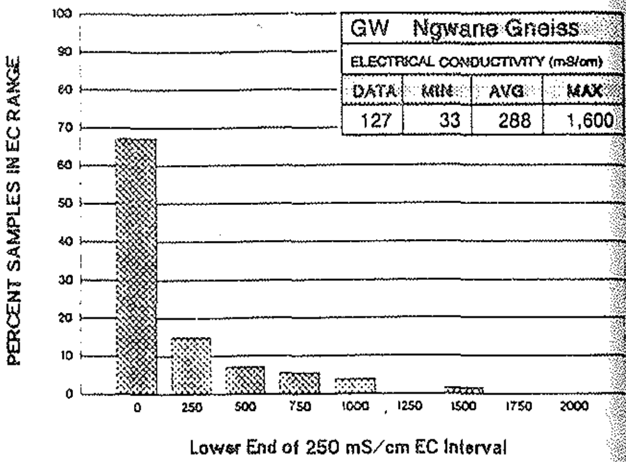
HISTOGRAM OF MAJOR ION GROUNDWATER CHEMISTRY BY UNIT TYPE

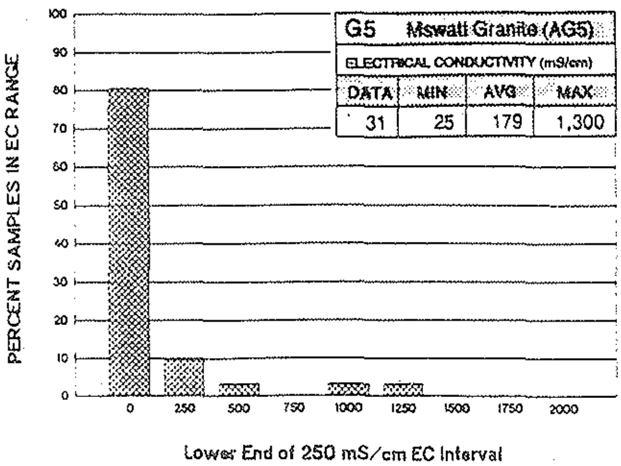
FIGURE: 4

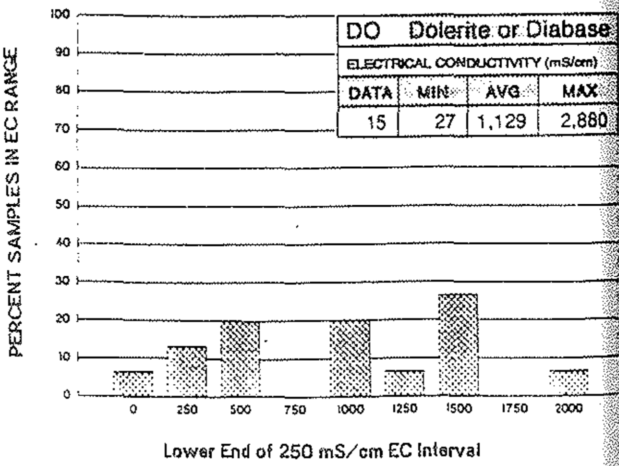

GD Granodiorite (Usutu)
ELECTRICAL CONDUCTIVITY (mS/cm)
DATA MIN AVG MAX
64 50 246 4,000
PERCENT SAMPLES IN EC RANGE
0 250 500 750 1000 1250 1500 1750 2000
Lower End of 250 mS/cm EC Interval

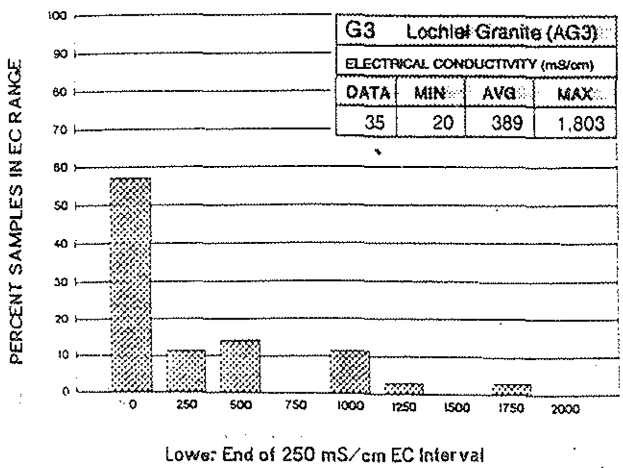

GN Other Gneisses
ELECTRICAL CONDUCTIVITY (mS/cm)
DATA MIN AVG MAX
24 26 118 250
PERCENT SAMPLES IN EC RANGE
0 250 500 750 1000 1250 1500 1750 2000
Lower End of 250 mS/cm EC Interval

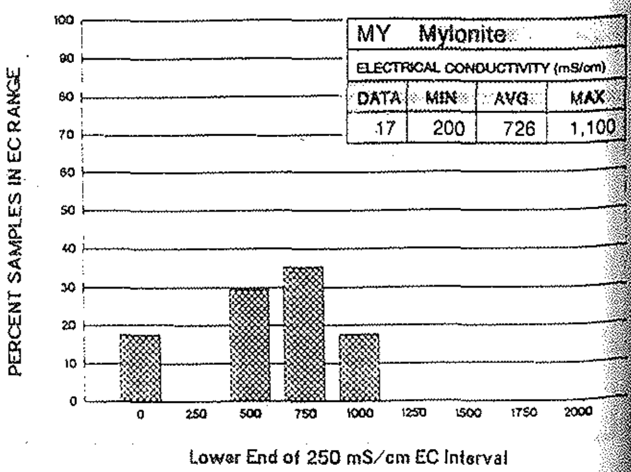

GR Other Granites
ELECTRICAL CONDUCTIVITY (mS/cm)
DATA MIN AVG MAX
13 20 224 920
PERCENT SAMPLES IN EC RANGE
0 250 500 750 1000 1250 1500 1750 2000
Lower End of 250 mS/cm EC Interval

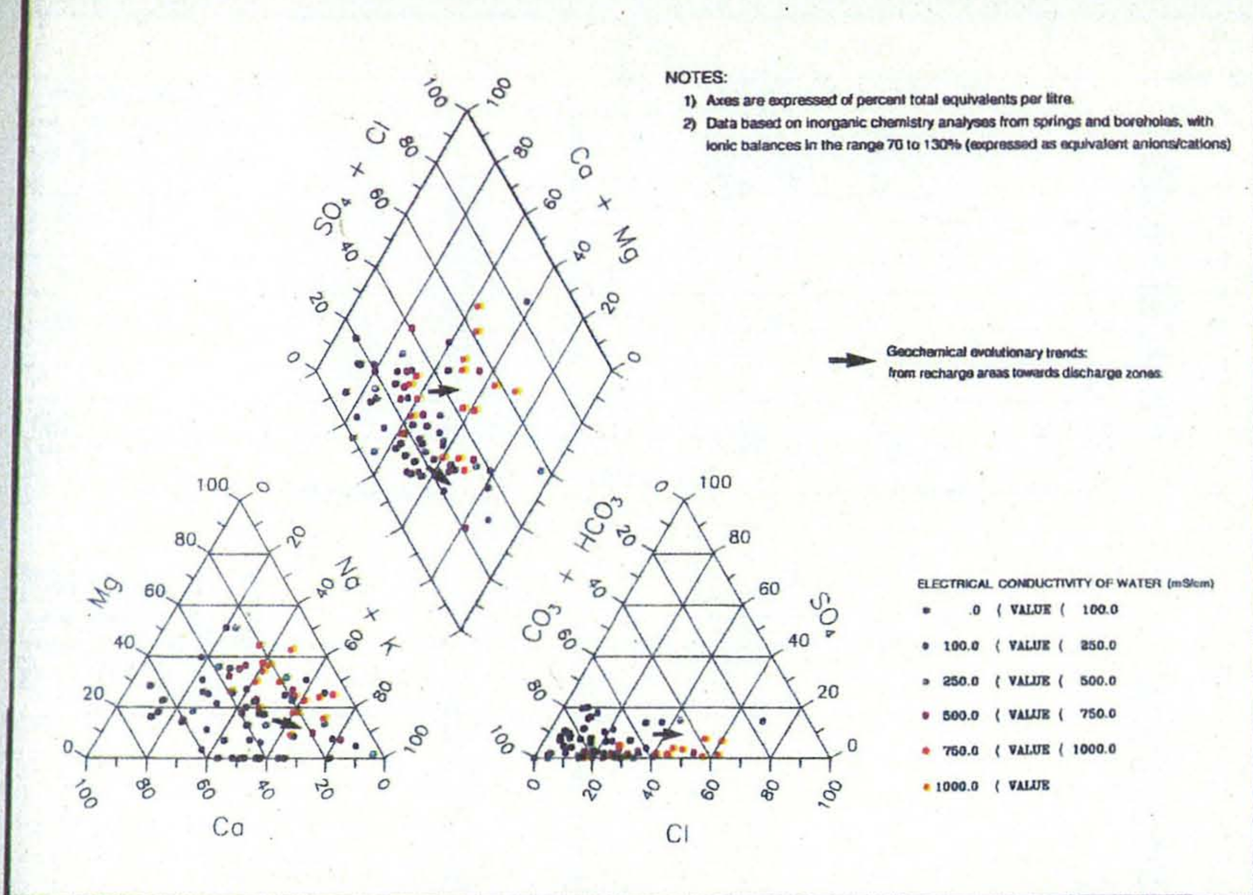

GW Ngwane Gneiss
ELECTRICAL CONDUCTIVITY (mS/cm)
DATA MIN AVG MAX
127 33 288 1,600
PERCENT SAMPLES IN EC RANGE
0 250 500 750 1000 1250 1500 1750 2000
Lower End of 250 mS/cm EC Interval


G5 Mswati Granite (AG5)
ELECTRICAL CONDUCTIVITY (mS/cm)
DATA MIN AVG MAX
31 25 179 1,300
PERCENT SAMPLES IN EC RANGE
0 250 500 750 1000 1250 1500 1750 2000
Lower End of 250 mS/cm EC Interval

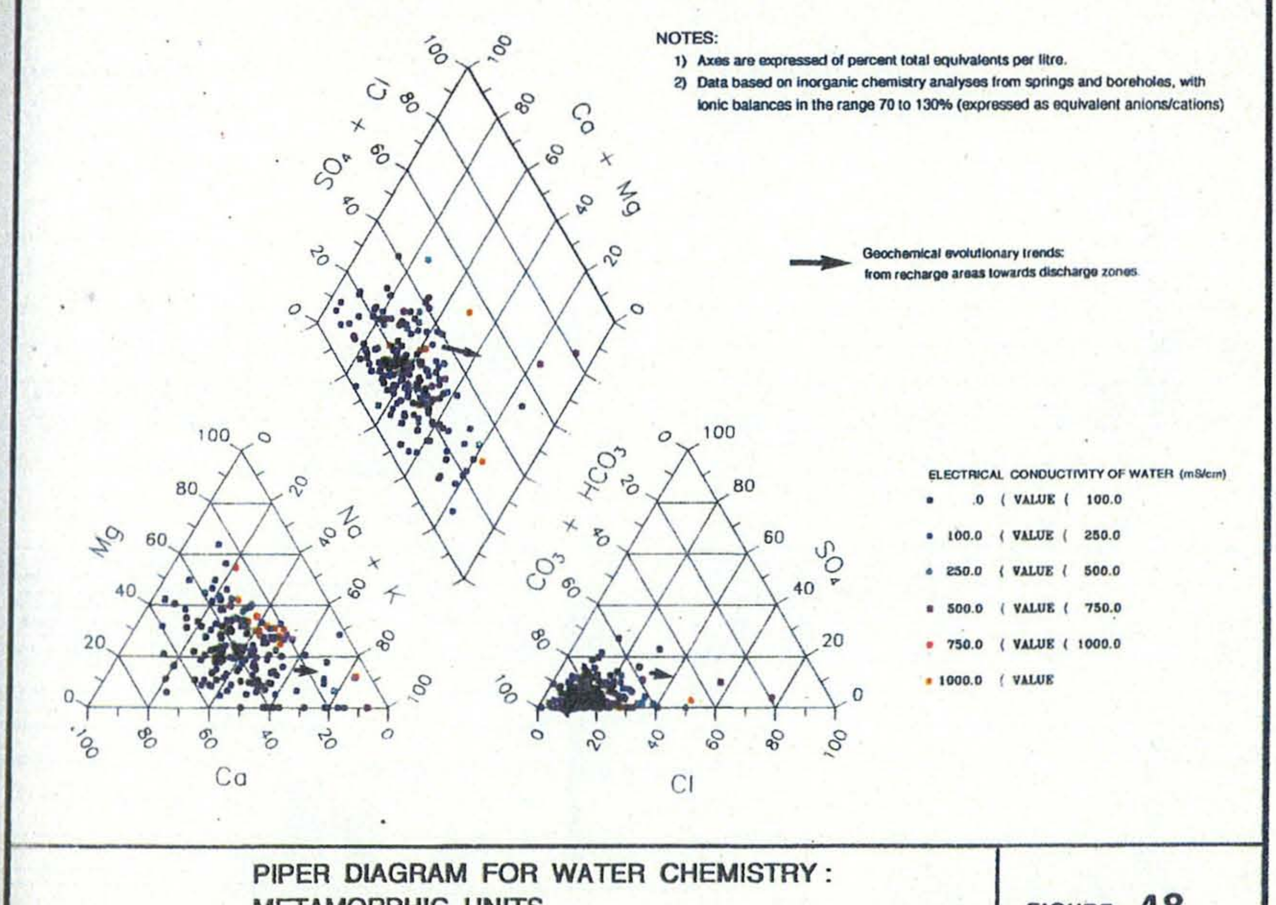

DO Dolerite or Diabase
ELECTRICAL CONDUCTIVITY (mS/cm)
DATA MIN AVG MAX
15 27 1,129 2,880
PERCENT SAMPLES IN EC RANGE
0 250 500 750 1000 1250 1500 1750 2000
Lower End of 250 mS/cm EC Interval


G3 Lochiel Granite (AG3)
ELECTRICAL CONDUCTIVITY (mS/cm)
DATA MIN AVG MAX
35 20 389 1,803
PERCENT SAMPLES IN EC RANGE
0 250 500 750 1000 1250 1500 1750 2000
Lower End of 250 mS/cm EC Interval

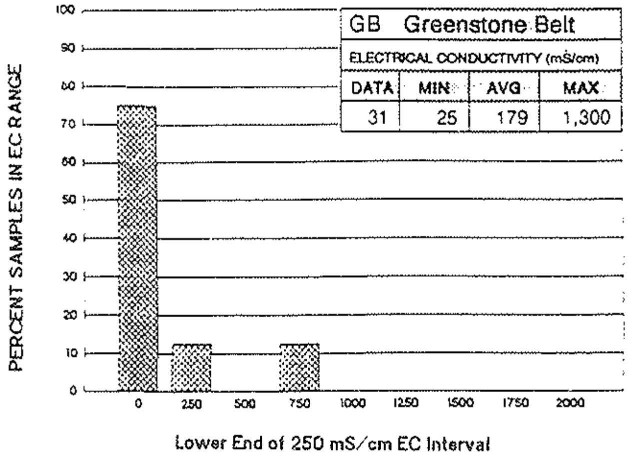

MY Mylonite
ELECTRICAL CONDUCTIVITY (mS/cm)
DATA MIN AVG MAX
17 200 726 1,100
PERCENT SAMPLES IN EC RANGE
0 250 500 750 1000 1250 1500 1750 2000
Lower End of 250 mS/cm EC Interval



PIPER DIAGRAM FOR WATER CHEMISTRY: GRANITIC UNITS — FIGURE: 47

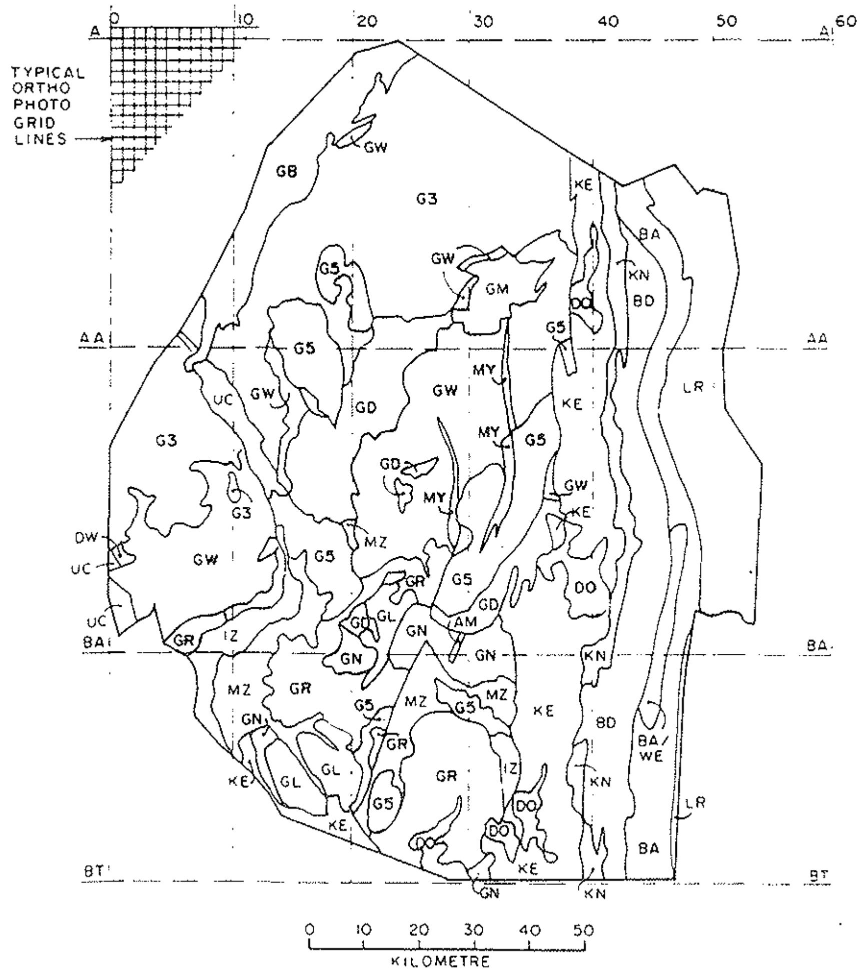


PIPER DIAGRAM FOR WATER CHEMISTRY: METAMORPHIC UNITS — FIGURE: 48



NOTES:

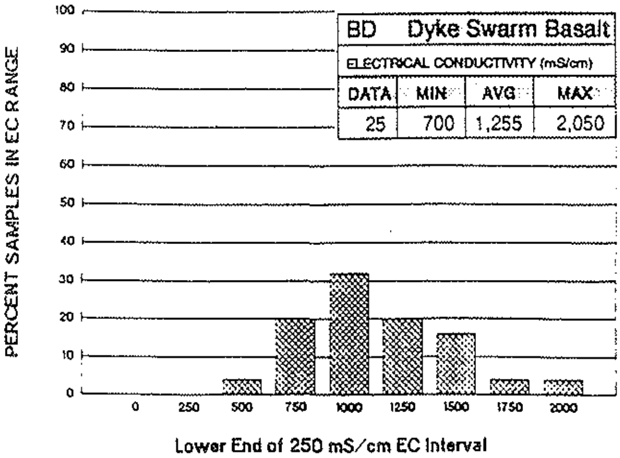
1) Only hydrogeological units with more than six sets of data are represented in the graphs.
2) For more information on the units, see data on Tables III and IV.
3) Data sets include springs

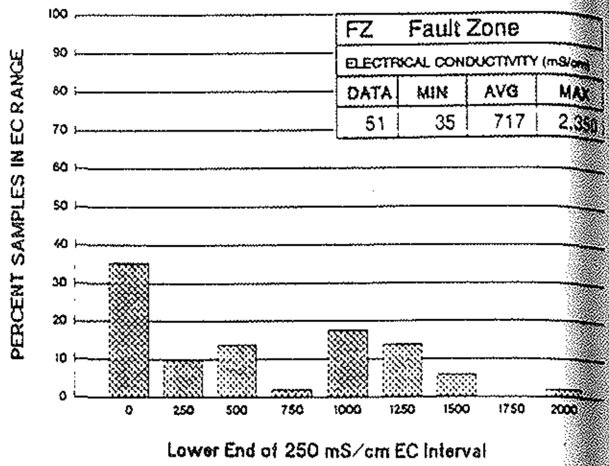


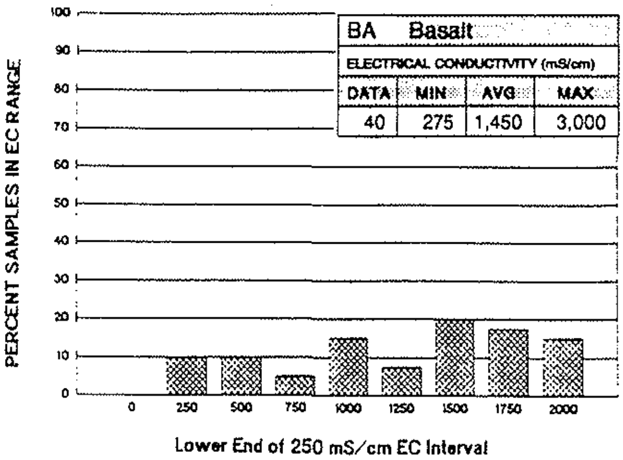
SIMPLIFIED HYDROGEOLOGIC MAP

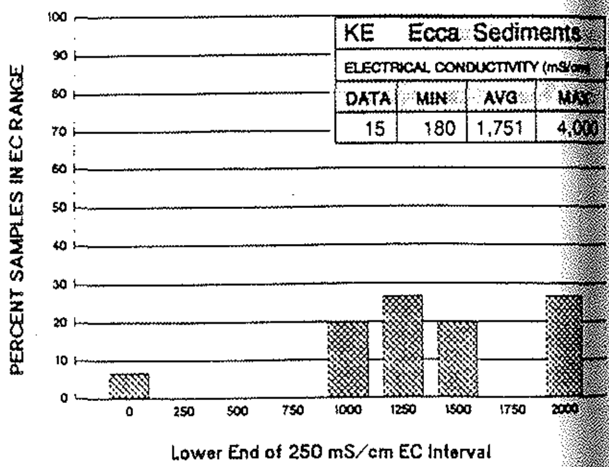
ELECTRICAL CONDUCTIVITY OF GROUNDWATER : GRANITIC AND METAMORPHIC UNITS

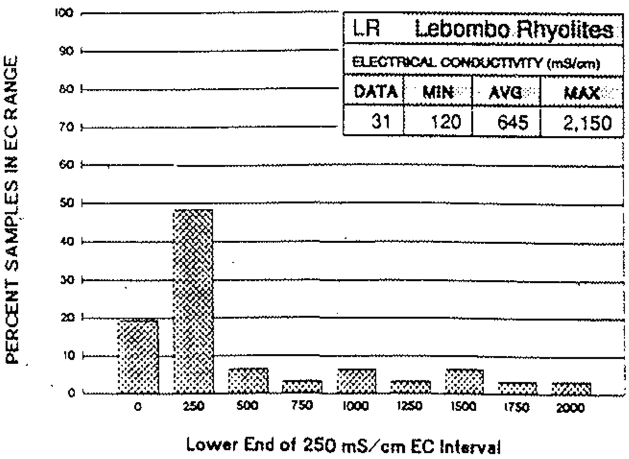
FIGURE: 49

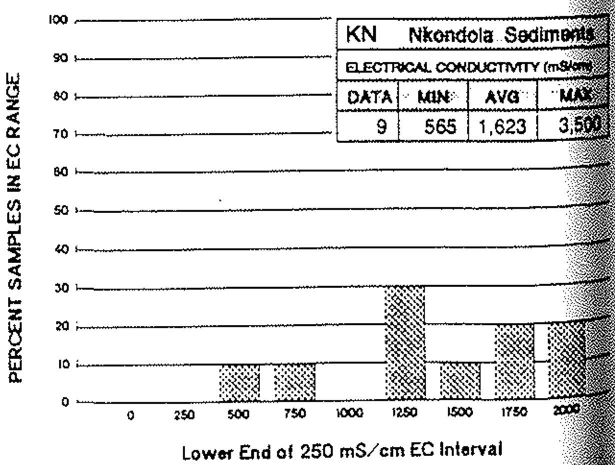

BD Dyke Swarm Basalt
ELECTRICAL CONDUCTIVITY (mS/cm)
DATA MIN AVG MAX
25 700 1,255 2,050
PERCENT SAMPLES IN EC RANGE
Lower End of 250 mS/cm EC Interval


FZ Fault Zone
ELECTRICAL CONDUCTIVITY (mS/cm)
DATA MIN AVG MAX
51 35 717 2,35
PERCENT SAMPLES IN EC RANGE
Lower End of 250 mS/cm EC Interval


BA Basalt
ELECTRICAL CONDUCTIVITY (mS/cm)
DATA MIN AVG MAX
40 275 1,450 3,000
PERCENT SAMPLES IN EC RANGE
Lower End of 250 mS/cm EC Interval

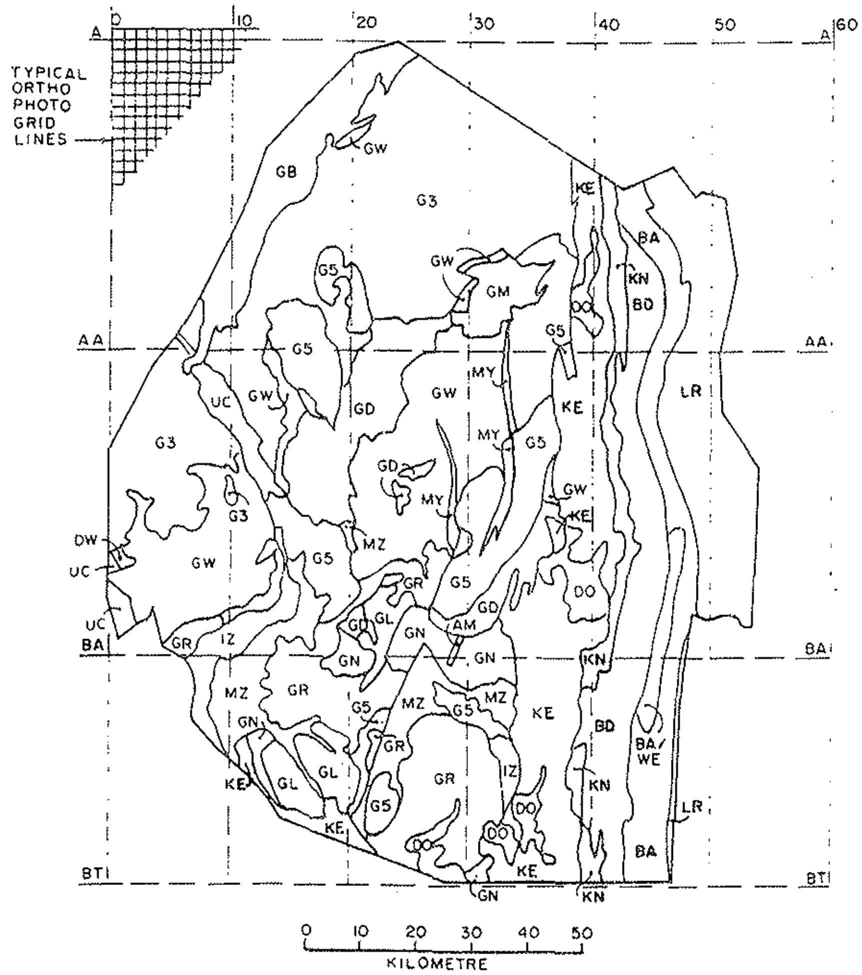

KE Ecca Sediments
ELECTRICAL CONDUCTIVITY (mS/cm)
DATA MIN AVG MAX
15 180 1,751 4,000
PERCENT SAMPLES IN EC RANGE
Lower End of 250 mS/cm EC Interval


LR Lebombo Rhyolites
ELECTRICAL CONDUCTIVITY (mS/cm)
DATA MIN AVG MAX
31 120 645 2,150
PERCENT SAMPLES IN EC RANGE
Lower End of 250 mS/cm EC Interval


KN Nkondola Sediments
ELECTRICAL CONDUCTIVITY (mS/cm)
DATA MIN AVG MAX
9 565 1,623 3,500
PERCENT SAMPLES IN EC RANGE
Lower End of 250 mS/cm EC Interval

NOTES:

1) Only hydrogeological units with more than six sets of data are represented in the graphs.
2) For more information on the units, see data on Tables III and IV.
3) Data sets include springs

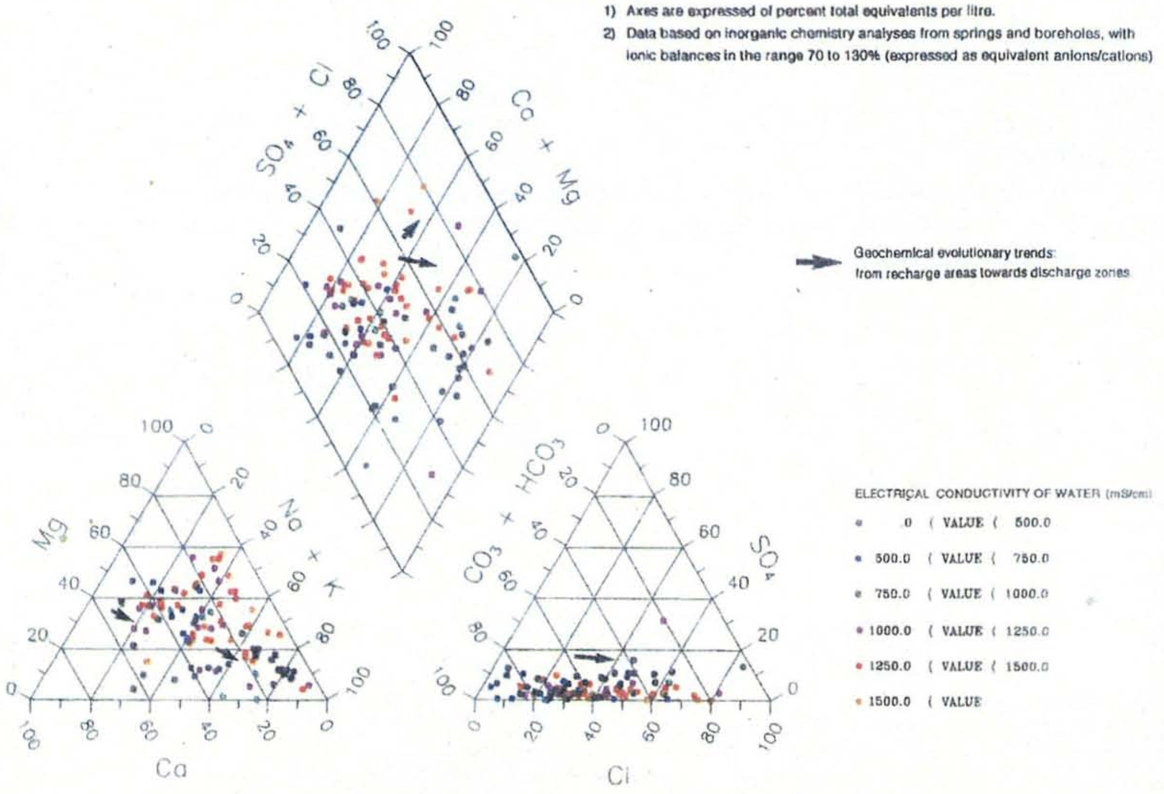


SIMPLIFIED HYDROGEOLOGIC MAP

ELECTRICAL CONDUCTIVITY OF WATER:
VOLCANIC AND SEDIMENTARY UNITS, AND FAULT ZONES

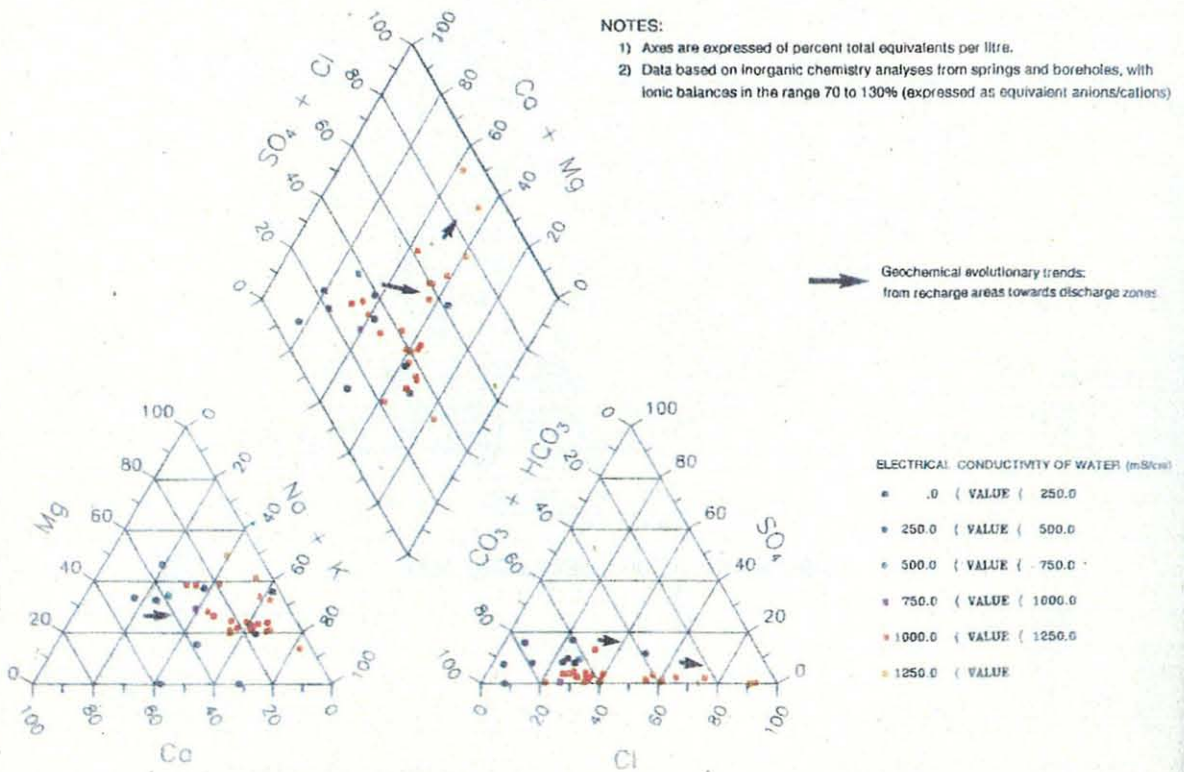
FIGURE: 50

NOTES:
1) Axes are expressed of percent total equivalents per litre.
2) Data based on inorganic chemistry analyses from springs and boreholes, with ionic balances in the range 70 to 130% (expressed as equivalent anions/cations)

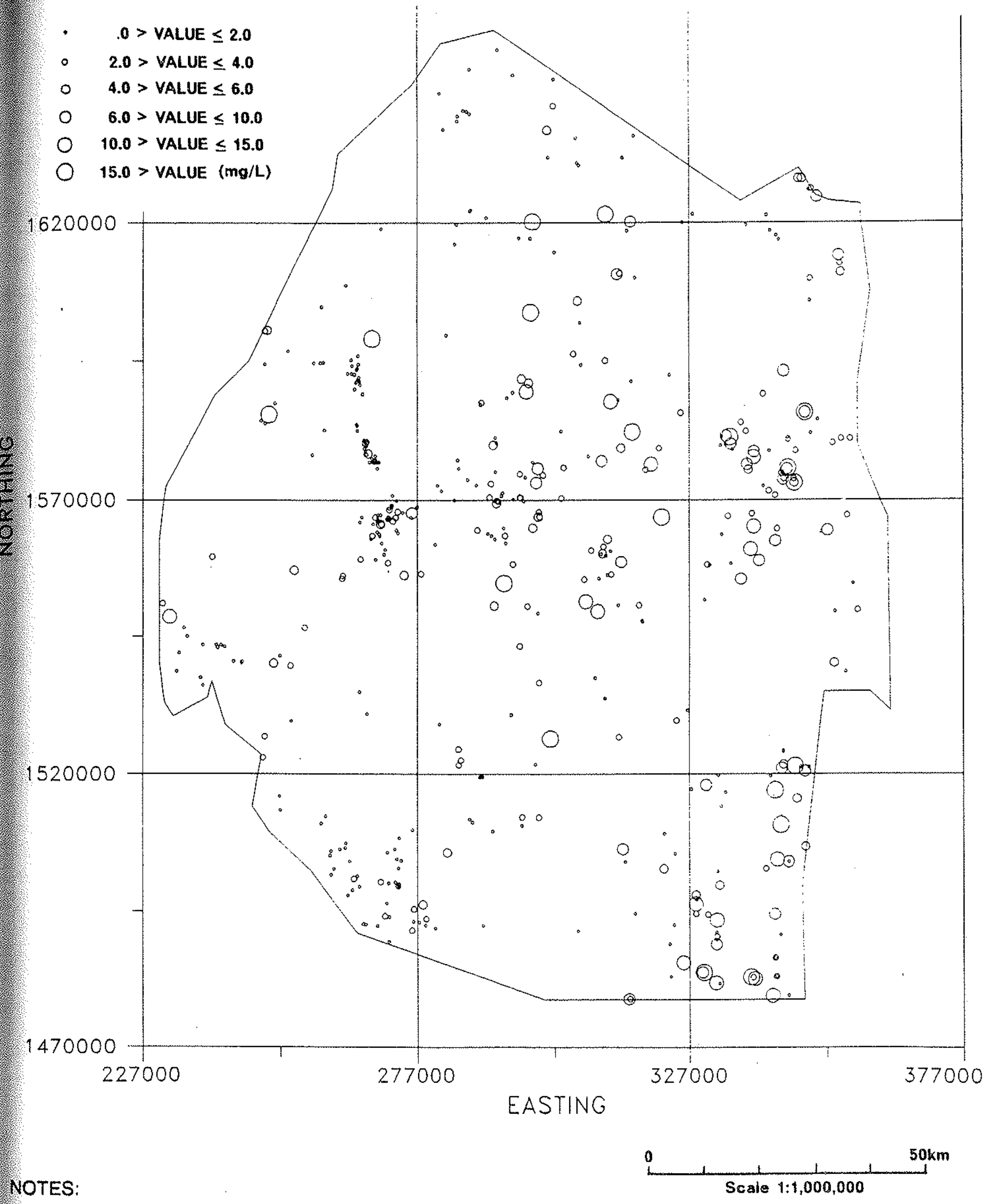


PIPER DIAGRAM FOR WATER CHEMISTRY : VOLCANIC UNITS | FIGURE: 51

NOTES:
1) Axes are expressed of percent total equivalents per litre.
2) Data based on inorganic chemistry analyses from springs and boreholes, with ionic balances in the range 70 to 130% (expressed as equivalent anions/cations)



PIPER DIAGRAM FOR WATER CHEMISTRY : SEDIMENTARY UNITS | FIGURE: 52

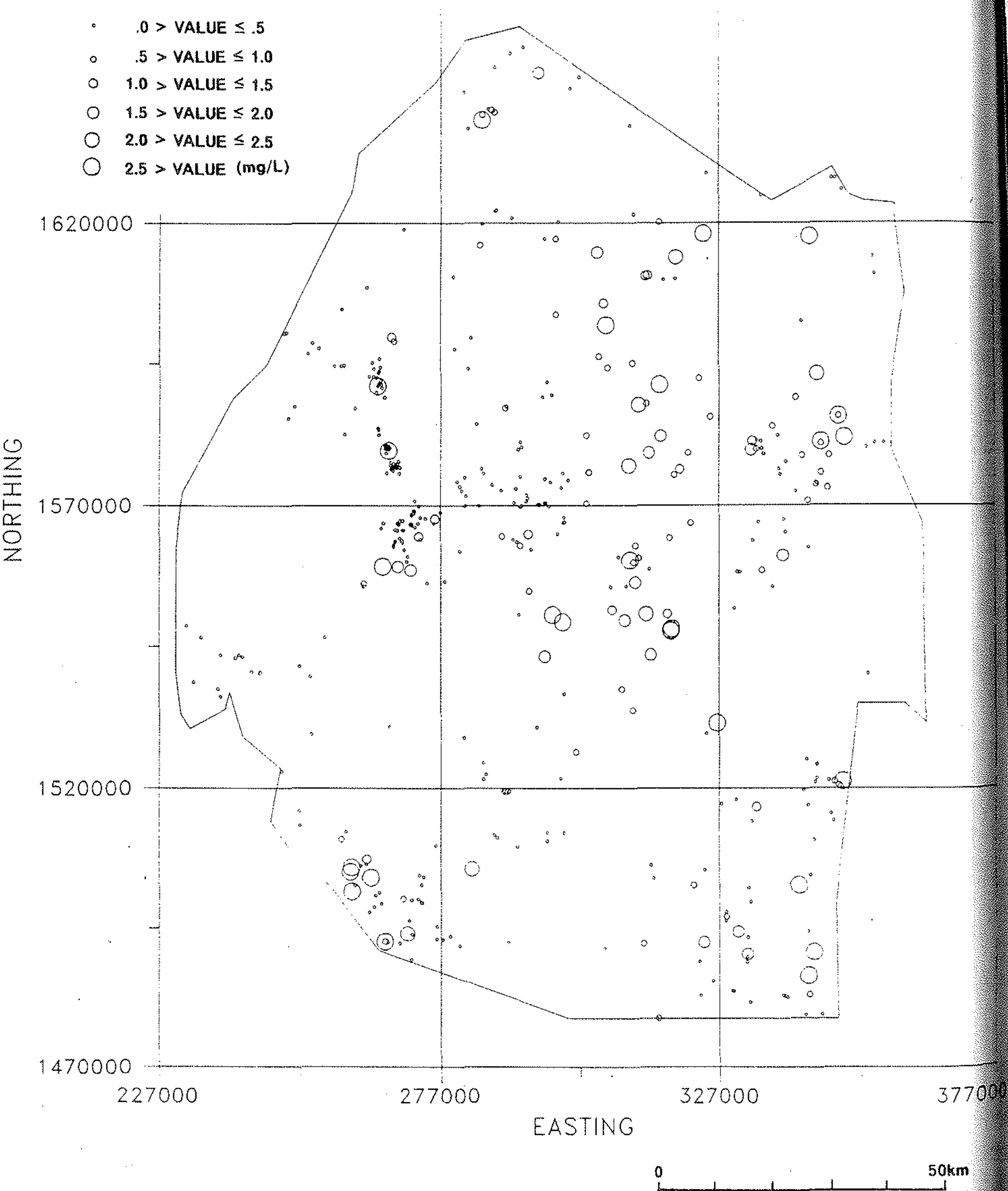


NOTES:

1) Values expresed in mg/L.
2) Data based on inorganic chemistry analyses from springs and boreholes, with ionic balances in the range 70 to 130% (expressed as equivalent anions/cations)

DISTRIBUTION OF NITRATE IN GROUNDWATERS

FIGURE: 53

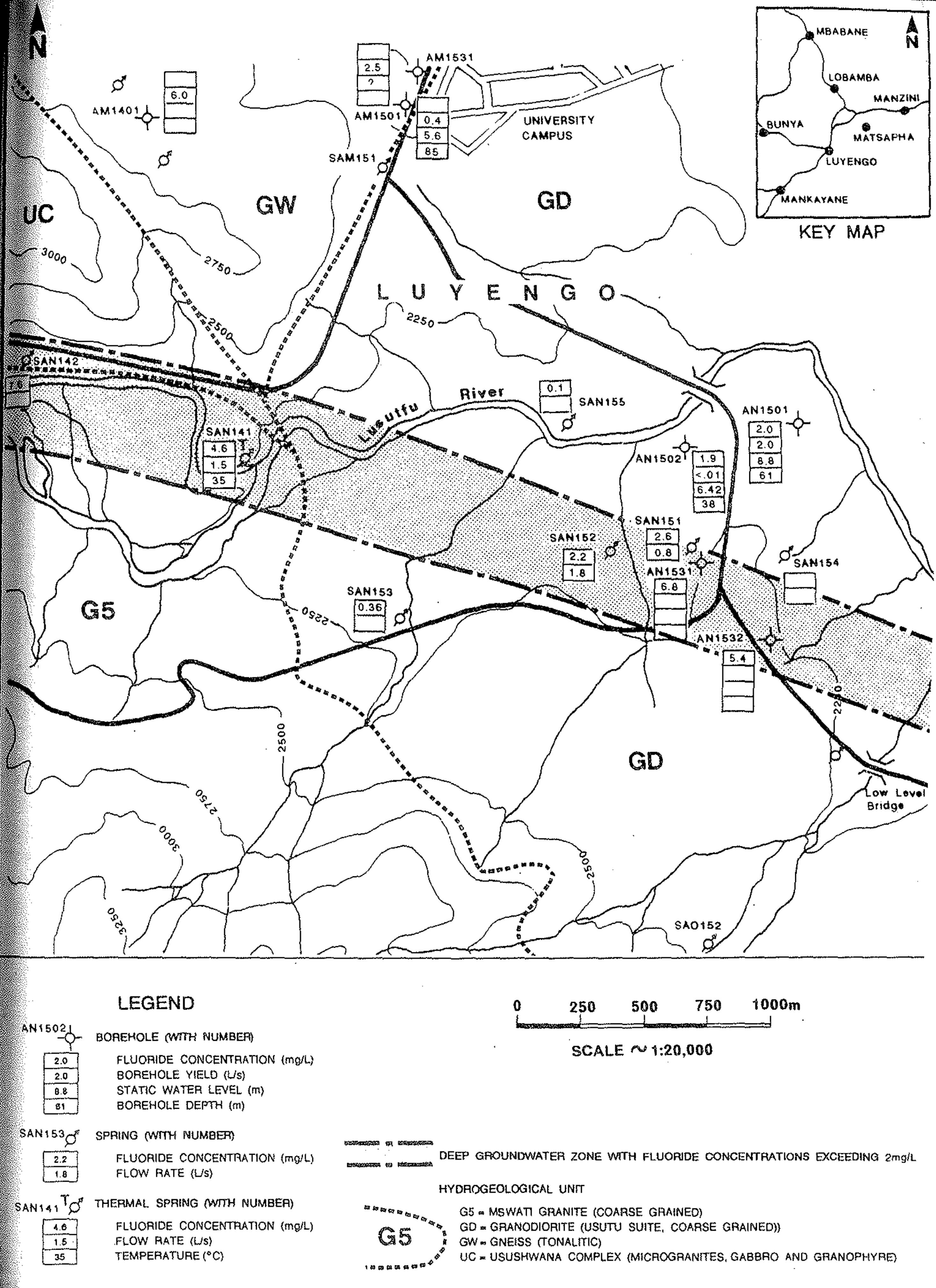


NOTES:

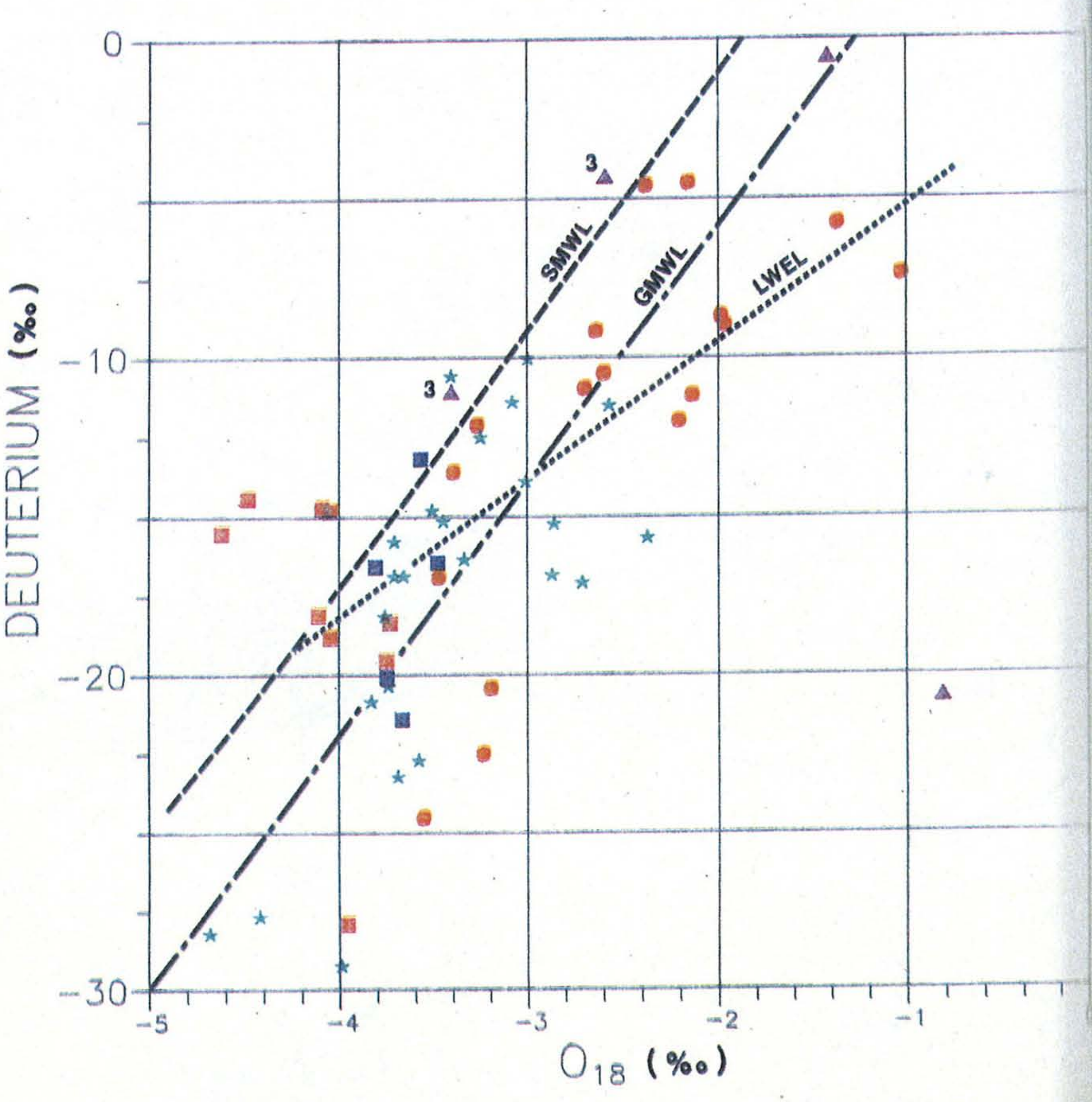
1) Values expresed in mg/L.
2) Data based on inorganic chemistry analyses from springs and boreholes, with ionic balances in the range 70 to 130% (expressed as equivalent anions/cations)

DISTRIBUTION OF FLUORIDE IN GROUNDWATERS

FIGURE: 5



FLUORIDE IN GROUNDWATER IN LUYENGO AREA FIGURE: 55



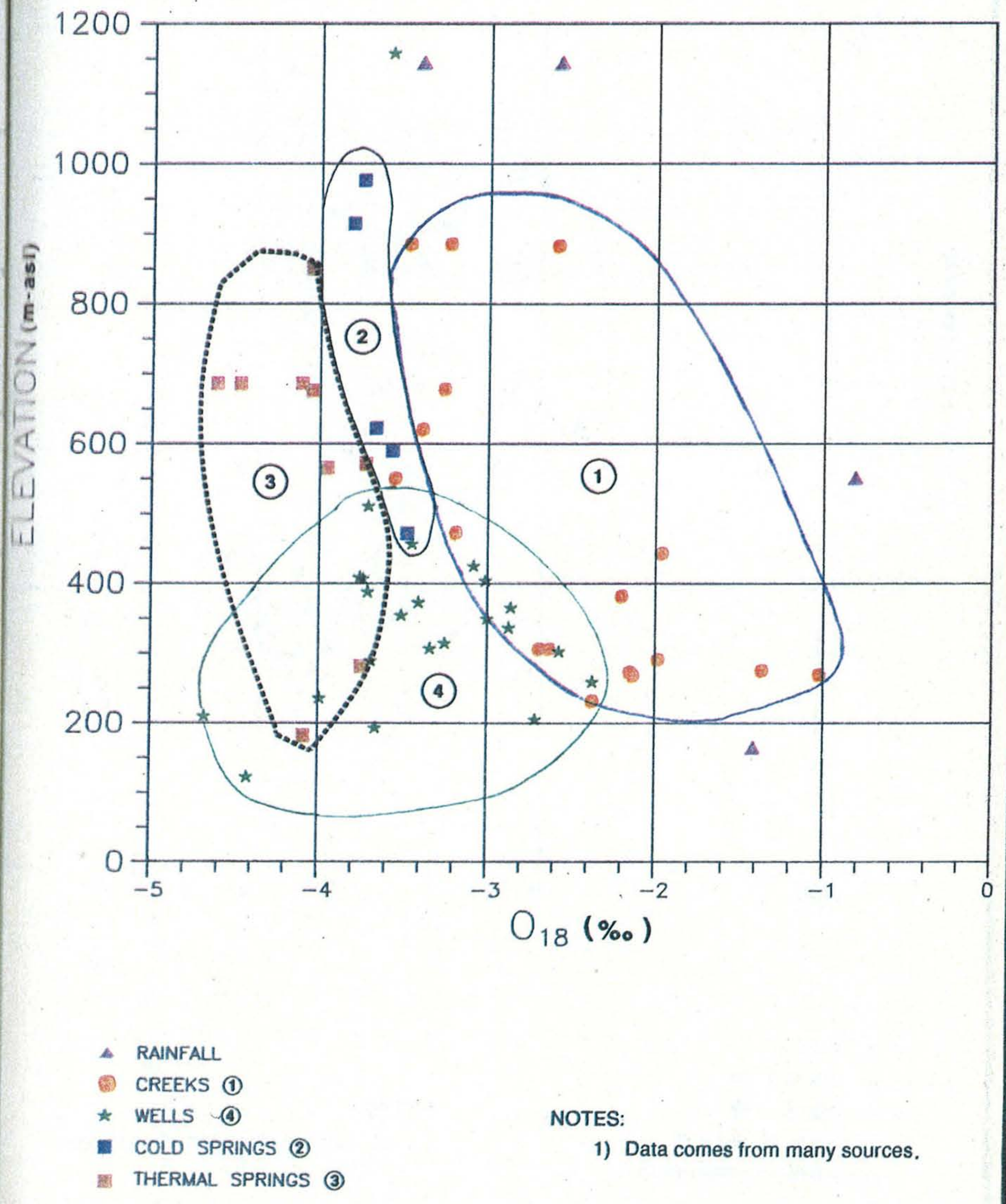
LEGEND

- GLOBAL METEORIC WATER LINE GMWL ($\delta D = 8\delta^{18}O + 10$)
- LOCAL (SWAZILAND) METEORIC WATER LINE SMWL[2] ($\delta D = 7.8\ \delta^{18}O + 14$)
- LOCAL WATER EVAPORITIC LINE ($\delta D = 5\ \delta^{18}O$)
- ▲ RAINFALL[3]
- ● CREEKS
- ★ WELLS
- ■ COLD SPRINGS
- ■ THERMAL SPRINGS

NOTES:

1) Data comes from many sources.
2) Based on runoff samples only.
3) Denotes Mbabane rainfall samples.

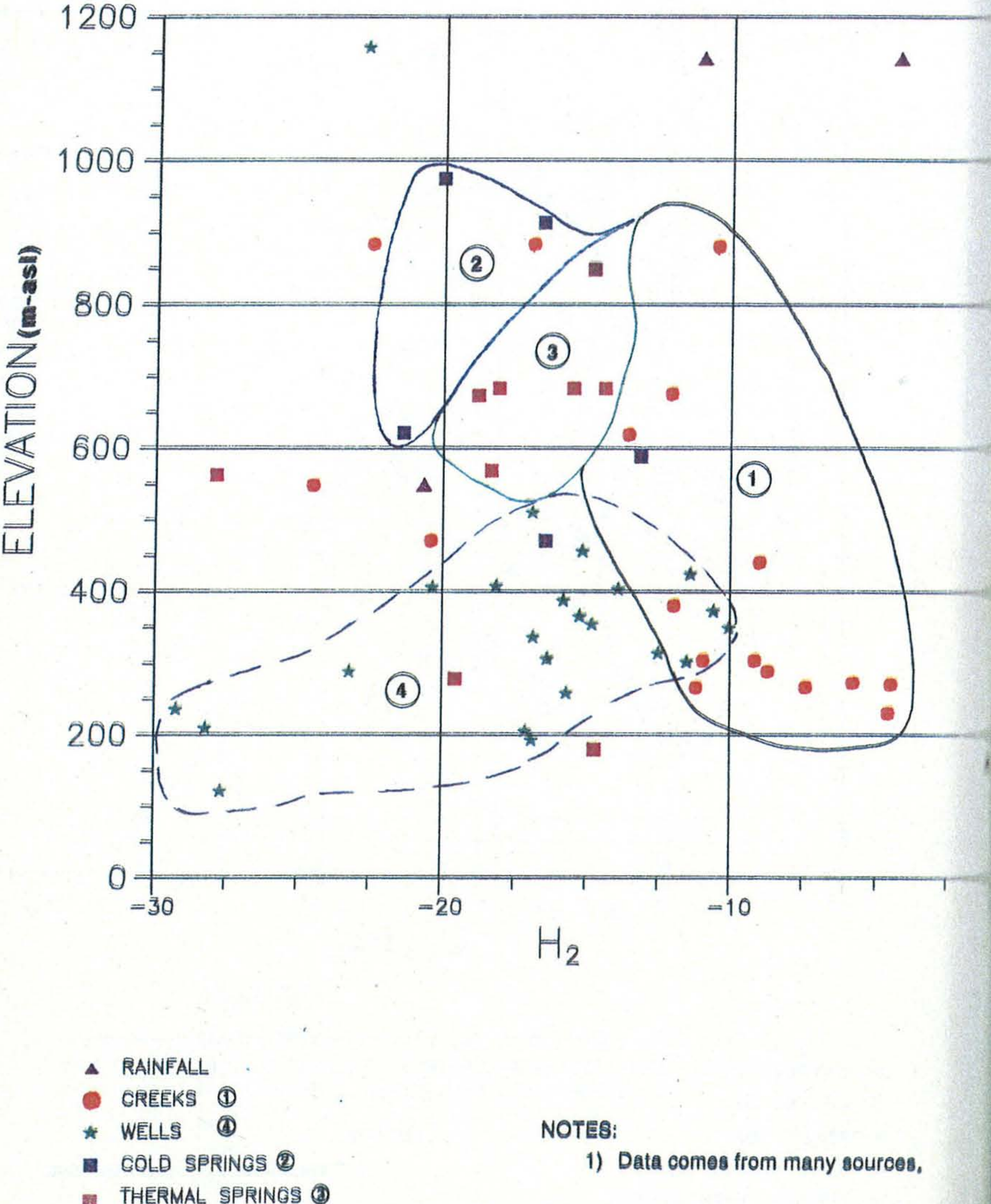
OXYGEN-18 VS, DEUTERIUM ISOTOPES IN WATER | **FIGURE: 5[illegible]**



NOTES:

1) Data comes from many sources.

OXYGEN-18 ISOTOPES IN WATER VS. ELEVATION



NOTES:

1) Data comes from many sources.

DEUTERIUM ISOTOPES IN WATER VS. ELEVATION | **FIGURE:**

TABLE : V DISTRIBUTION OF BOREHOLE YIELDS BY UNIT TYPE

UNIT TYPE	BLOWN YIELD (L/s)																		TOTAL BOREHOLES			
MAJOR	From To 0.01	0.01 0.5	0.5 1.0	1.0 1.5	1.5 2.0	2.0 2.5	2.5 3.0	3.0 3.5	3.5 4.0	4.0 4.5	4.5 5.0	5.0 5.5	5.5 6.0	6.0 6.5	6.5 7.0	7.0 7.5	7.5 8.0	>8.0 20	WITH YIELDS	NO DATA	ALL	% ALL
BA	8	22	12	8	4	1	1				1				4				61	16	77	5.66
BA*	10	27	18	9	11	3	1	3			1				5				88	17	105	7.72
BA/WE	1	4	3	1	7	2		2							1				21		21	1.54
BD	14	38	15	5	1	4	2	1	2						1				83	17	100	7.35
BD*	14	39	17	5	1	4	2	1	2						1				86	17	103	7.57
DO	10	7	3	1	1	2					1								25	6	31	2.28
DO*	11	9	5	2	2	3	1		1		1								35	7	42	3.09
FZ*	6	11	16	6	9	2	1	2	2		4				6			5	70	11	81	5.96
G3	11	25	4	6	3	4	1		2		3				1				60	19	79	5.81
G3/DO	5	5	1				1		1						1				14	14	28	2.06
G3*	16	30	8	6	3	5	2		3		5				2				80	21	101	7.43
G5	3	6	6	2		2	1				1								21	10	31	2.28
G5*	7	10	6	2	2	2	1				1								31	10	41	3.01
GD	7	8	4	5		3	5		1		1								34	23	57	4.19
GD*	9	23	18	12	12	6	8		3	1	2				2			1	97	66	163	11.9
GD/WE		14	13	6	9	3	1		1	1	1				1			1	51	41	92	6.76
GL	8	2		2		1	2				1							1	17	15	32	2.35
GL*	8	2	1	2	1	2	2		1		1							1	21	15	36	2.64
GN	5	4	3		2	3	2		2										21	5	26	1.91
GN*	6	4	3		2	3	2		3										23	7	30	2.20
GR	3	9	1	9		1	1		1		1								26	6	32	2.35
GR*	3	10	2	9		1	1		1		2								29	7	36	2.64
GW	9	32	12	7	6	8	3	1	4		3					1		2	88	63	151	11.1
GW*	12	49	34	11	12	11	11	2	9		6			1	1	1		3	163	107	270	19.8
GW/WE	1	12	15	1	4		7	1	2		2			1					46	40	86	6.32
KE	11	18	7	2	2	1			1										42	24	66	4.85
KE*	20	34	11	3	4	1			3		1								77	28	105	7.72
KE/DO	7	13	2	1	2				1										26	3	29	2.13
KN	2	11	6	1	2	3	1	1	2									2	31	12	43	3.16
KN*	3	13	6	1	2	5	1	1	2									2	36	13	49	3.60
LR	6	12	6			1			1	1									27	14	41	3.01
LR*	7	15	6	1	1	1			1	1									33	15	48	3.53
MY	4	5	3	1	1												1		15	11	26	1.91
MY*	5	7	4	2	1												1		20	11	31	2.28
MZ*	2	1	3	2	1		3		1		2				1				16	9	25	1.83
Undefined																					68	5.00
TOTAL:	141	285	161	75	65	49	39	9	33	-2	28			1	19	1	1	12	921	370	1359	100
% of Total	15.3	30.9	17.5	8.1	7.1	5.3	4.2	1.0	3.6	0.22	3.0			0.11	2.1	0.11	0.11	1.3	100	28.659		
Cum % Total	15.3	46.3	63.7	71.9	78.9	84.3	88.5	89.5	93.1	93.3	96.3	96.3	96.3	96.4	98.5	98.6	98.7	100				

NOTE: * Signifies that all boreholes with this hydrogeologic unit specified, whether a major or minor unit (i.e."All Types")

TABLE : VI SUMMARY OF DATA ON SELECTED DISCHARGE ZONES

HYDROGEOLOGICAL UNIT	NO. OF SPRINGS	DISCHARGE (L/s)			WATER							SPRING WITH MAXIMUM FLOW RATE			
					CHEM. DATA.	E.C. (μS/cm)			TEMP (°C)						
		Min	Max	Avg		Min	Max	Avg	Min	Max	Avg	Spring Name	Flow (L/s)	Elev (m)	Map S
AL	2	1.5	1.5	1.5	0	NA	NA	NA	NA	NA	NA	S_B251	1.5	412	2
AM	4	0.5	4.6	0.8	0	130	200	157	24	24	24	SBM131	4.6	NA	28
BA	2	0.8	0.8	0.8	1	275	275	275	23	23	23	SAG441	0.8	612	14
BD	1	NA	NA	NA	1	788	788	788	NA	NA	NA	SAI441	NA	343	14
DO	4	1.0	9.3	5.2	2	27	400	214	NA	NA	NA	SBO151	9.3	NA	28
FZ	10	0.6	7.4	2.8	2	28	390	236	19	21	20	S_J201	7.4	680	2
GB	6	0.2	5.6	2.4	1	75	75	75	NA	NA	NA	S_E211	5.6	555	2
GD	21	0.3	9.6	3.0	8	38	640	310	22	44	37	SAN181	9.6	181	19
GM	1	3.0	3.0	3.0	1			410			38	S_T351	3.0	296	7
GN	14	0.3	55.6	6.8	6	5	200	148	20	33	26	SBA281	56.6	NA	24
GW	41	0.2	48.0	5.6	12	33	516	165	22	45	30	SAR131	63.7	NA	17
GR	14	0.3	22.7	5.0	1	40	400	132	NA	NA	NA	SBJ271	42.5	NA	29
G3	55	0.1	9.6	1.4	5	20	200	56	16	52	32	SAI051	9.6	1260	10
G5	54	0.1	49.6	4.0	16	21	210	63	14	52	24	SBM232	49.6	850	29
IZ	12	0.1	4.8	1.2	0	45	80	62	23	23	23	SAZ082	4.8	NA	22
KE	5	0.1	4.1	2.6	0	100	150	125	NA	NA	NA	SB0152	4.1	NA	28
LA	1	2.3	2.3	2.3	0	NA	NA	NA	NA	NA	NA	S_G201	2.3	630	2
MG	2	0.4	0.4	0.4	0	110	110	110	NA	NA	NA	SAX091	0.4	NA	23
MY	9	0.1	1.1	0.5	2	200	247	224	26	26	26	SAN332	1.1	309	19
MZ	6	0.3	3.9	2.0	2	40	210	121	17	17	17	SBG241	3.9	745	29
SC	1	NA	NA	NA	0	NA	NA	NA	NA	NA	NA	S_Y091	NA	NA	11
SH	1	0.8	0.8	0.8	0	NA	NA	NA	NA	NA	NA	S_D221	0.8	500	2
SS	1	0.7	0.7	0.7	1	200	200	200	NA	NA	NA	S_M471	0.7	559	4
UC	9	0.5	1.3	0.9	0	20	20	20	NA	NA	NA	SAC093	1.3	NA	11
TOTAL:	276	0.1	55.6	2.4	61	5	788	195	5	52	27				

NOTES: 1) E.C. = ELECTRICAL CONDUCTIVITY

2) TEMP = TEMPERATURE

APPENDIX A

GLOSSARY OF HYDROGEOLOGICAL TERMS

APPENDIX: A

GLOSSARY OF SELECTED HYDROGEOLOGICAL TERMS

A-horizon: The uppermost zone in the soil profile, from which soluble salts and colloids have been leached and in which organic matter has accumulated. This is also known as the zone of leaching

Absorption: Refers to the trapping of molecules or ions within the internal structure of the solid.

Acid: Of a substance; that reacts with water to yield hydronium (or hydrogen) ions H_3CO_3) reacts incompletely; hence (H^+) = (HC1). A weak acid (e.g. H_2CO_3) reacts incompletely and equilibrium is established.)

Acidity: Of a water; is the capacity of the water to donate protons (i.e. includes the un-ionized protons of weakly ionizing acids such as H_2CO_3 and tannic acid, as well as hydrolyzing salts such as ferrous and/or aluminum sulphate). Normally expressed as mg/L $CaCO_3$.

Adsorption: The attraction and adhesion of layer of ions from an aqueous solution to the solid mineral surfaces with which it is in contact.

Advection: Process of contaminant transport by which solutes are moved by bulk motion of flowing groundwater.

Alkali soil: A soil that contains sufficient exchangeable Na^+ to interfere with the growth of most crop plants either with or without appreciable quantities of non-soluble salts.

Alkalinity: The capacity of water to accept protons (usually interpreted by the HCO_3^{-1} , CO_3^{+2}, OH^- components), normally expressed as $CaCO_3$.

Alluvial Fan: A fan shaped deposit of alluvium laid down by a stream where it emerges from an upland into less steeply sloping terrain.

Altitude Effect: The decrease in oxygen-18 and deuterium isotope contents in precipitation at increased elevations.

Anisotropy: Variation of a hydraulic property in a porous medium as a function of flow direction.

Aquiclude: A geologic formation which has an extremely low permeability when compared to an adjacent aquifer.

Aquifer: A geologic formation, group of formations or part of a formation, that contains sufficient saturated permeable material to yield significant quantities of water to wells, boreholes and springs. Several types of aquifers can exist.

i) *Confined aquifer (artesian)*: contains water under sufficient pressure that water levels in wells tapping it rise above the bottom of the confining bed.

ii) *Unconfined aquifer*: the water table is located within the formation.

Aquitard: A geologic formation which has appreciably greater permeability than an aquiclude, but considerably lower permeability than an aquifer.

Artesian: Refers to groundwater under sufficient hydrostatic head to rise above the aquifer containing it.

Attenuation: The decreased of the maximum concentration of a given constituent in a solution as a function of time or distance travelled along a flow path. It is related to a pulse of solute injected into a flowing solution. Attenuation is, therefore, caused by both adsorption and by dispersion.

B-horizon: The lower soil zone which is enriched by the deposition or precipitation of material from the overlying A-horizon. This is also known as the zone of accumulation.

Base Exchange Capacity: See Cation Exchange

Baseflow: That part of stream discharge derived from groundwater seeping into the stream with respect to time.

Baseflow Recession: The declining rate of discharge of a stream fed only by baseflow for an extended period. Typically, a baseflow recession will be exponential.

BOD (Biochemical Oxygen Demand): A measure of the oxygen required to biochemically degrade organic, nitrogenous and inorganic materials (unit is mg/L).

Bog: An ombrotrophic peat land, which is extremely nutrient-poor, with acidic water and with a dominant Sphagnum moss vegetation.

Buffer: A mixture of a weak acid and conjugate base (e.g. H_2CO_3 and HCO_3^-) which provide pH stability.

Capillary: An interstice capable of holding water above the water table by a combination of adhesive and cohesive forces.

Cation Exchange Capacity (CEC): Ability of a geologic material to exchange cations adsorbed onto mineral surfaces (exchange sites) with cations in the groundwater. Expressed as the number of millequivalents of cations that can exchange in a material with a dry mass of 100g (meq/100g).

Clastic Rock: Rock composed of broken pieces of older rocks.

Cleat: Vertical fracture planes that are commonly found in coal.

COD: Chemical Oxygen Demand; is a measure of the oxygen equivalent of the organic matter content of a sample that is susceptible to oxidation by a strong chemical oxidant (Unit is mg/L).

Coefficient of Permeability (k): Ratio of flow velocity to driving force (hydraulic gradient) for viscous flow under saturated conditions of a specified liquid in a porous medium (m/s).

Cohesion: Cohesion in water refers to the attraction of water molecules to each other.

Colloidal: Size of particulate matter; lies between lower limit of suspended matter and upper limit of dissolved solids.

Colluvium: A sediment deposit consisting of alluvium (river deposits) as angular fragments of the original rocks (e.g. talus, cliff debris, rock slides, avalanche material).

Consumptive Use: Of a plant - Water used by plants for transpiration and growth, water vapour loss from adjacent soil/snow and intercepted precipitation (units: equiv. depth of water per unit time).

Contaminant: Any solute that enters the hydrologic cycle through human action.

Contemporaneous: Of erosion - Erosion accomplished during a short cessation in the build up of deposits, e.g. floodplains, deltas, etc.

Contiguous: Two adjoining bodies, e.g. laterally contiguous.

Darcy's Law: The law governing laminar water flow through soils may be expressed as: $Q = KiA$ where:

Q = rate of flow (m^3/s)
K = the hydraulic conductivity (m/s)
i = hydraulic gradient or head loss per unit distance travelled (dimensionless)
A = the cross-sectional area through which the flow occurs (m^2)

Darcy Velocity: Rate flow (Q) divided by the cross-sectional area through which flow occurs. i.e. $VD = Q/A = nV$ Where:

V = Velocity of flow (m/s)
n = porosity

Deflation: Of a geologic process - The removal of material from a beach or other land surface by wind action.

Dendritic: Of shape - Leaf like appearance, commonly refers to a drainage pattern.

Depressurization: A reduction of hydrostatic pressure.

Depocentre: Of a depositional environment - An area of maximum deposition.

Desorption: Ion exchange process whereby ions attached to geologic materials by ionic attraction or adsorption are released into solution in groundwater. Also see adsorption.

Desiccate: Of a process - Substance remaining after removal of moisture.

Detrital: Decomposed rock material consisting of mechanically derived clastic products.

Deuterium: Stable isotope of hydrogen (^2H) having one neutron and an atomic weight of 2.

Dewatering: Process of lowering the water table or piezometric surface by removing water from storage.

Diamicton: Of a material - An unsorted sediment containing a wide range of particle sizes, regardless of genesis.

Diffusion: Tendency for solutes to spread out in a porous medium due to the thermal kinetic energy of solute particles on a molecular scale. Is an important dispersive mechanism of contaminants in very low velocity groundwaters.

Dike: A tabular body of igneous rock that cuts across the structure of adjacent rocks or cuts massive rocks. Although most dikes result from the intrusion of magma, some are the result of metasomatic replacement.

Diluvium: Of a sedimentary deposit: Coarse superficial deposits of glacial and fluvio-glacial origin laid down during the ice age.

Dip: The angle at which a stratum or any planar feature is inclined from the horizontal. The dip is at a right angle to the strike.

Discharge Area: An area in which there are upward components of hydraulic head in the aquifer. Groundwater is flowing toward the surface in a discharge area and may escape as a spring, seep, river baseflow, or by evaporating and transpiration.

Disconformity: Unconformity between parallel strata.

Discordant: A term used to describe an igneous contact that cuts across the bedding or foliation of adjacent rocks.

Dispersed: Of a soil - Commonly clay which readily forms colloidal particles (characteristics: low permeability, will shrink, crack and become hard on drying and slake and become plastic on wetting).

Dispersion: Tendency for solutes to spread out from flow line along flow path as a result of mechanical mixing and diffusion.

Distal: Sediment consisting of fine clastics formed furthest from the source area. Also refers to distant.

Drawdown: The difference in evaluation between the static water level (before pumping or dewatering) and the water level measured in a well or piezometer after commencement of pumping or dewatering (m).

Drift: Of a glacial deposit - Any rock material, such as boulders, till, gravel, sand or clay, transported by a glacier and deposited by or from the ice on land or in water derived from the melting of the ice.

DO: Dissolved Oxygen; (unit: mg/L).

Dolerite: Fresh basaltic rocks, with ophitic texture (similar to diabase).

Donga: Gully that was created by erosion of unconsolidated or weakly cohesive sediments. Derived from the Zulu word "udonga" or washed-out water way.

Dy: Subaqueous, muddy, acid humus horizon on top of parent material; consists of amorphous precipitation of humus gels (has a high C/N ratio).

EC: Electric Conductivity of fluid; measured in units of milli Siemens per metre (mS/m), micro Siemens per centimetre (µS/cm) or micro mhos per centimetre (µmho/cm)

Echelon Faults: Geologic structure in rock consisting of separate faults having parallel but step-line trends.

Effective Size: Particle size of a soil - The size which 10% of the material is smaller than (i.e. 90% is retained).

Effluent: Flowing forth out of.

Effluent Seepage: Seepage out of the lithosphere.

Effluent Stream: Groundwater term used to describe a stream that is gaining groundwater along a given reach. (Note: A better term would be a gaining stream.)

Eh: A measure of the oxidizing or reducing tendency of a solution. It is measured in volts and is commonly called the redox potential and is defined as the energy gained in the transfer of 1 mole of electrons from an oxidant to H^2. It is related to the pE.

Elevation Head: The portion of fluid potential of hydraulic head attributable to the elevation above a datum of the point of measurement.

Eluvium: Derived from eluvial processes. A soil formed by transport of minerals by water percolating through weathering bedrock, either dissolved or in suspension, and then deposited at a lower depth. Typically, this is a red brown clay or silt, with other chemicals present (e.g. iron). Synonymous with saprolite. Laterite is an eluvium with dominant silica and traces of iron and aluminium hydroxides.

Environmental Isotopes: Naturally occurring isotopes existing in water in the hydrological cycle including the stable isotopes:

oxygen-18 (^{18}O)
deuterium (^{2}H)
carbon-13 (^{13}C)
sulphur-34 (^{34}S)

and the radioactive isotopes:
tritium (^{3}H)
carbon-14 (^{14}C)

Ephemeral: Of a stream - Flow occurs only in response to precipitation (i.e. no snow melt or groundwater seepage).

Equipotential Line: Two-dimensional representation of an equipotential surface (i.e. equal energy surface) in a specified hydrogeologic unit.

Equipotential Surface: Surface in a three-dimensional hydrogeological system representing locus of points of equal hydraulic head.

Equivalents per Litre (eq/L): Number of moles of solute multiplied by the valence of the solute species in one litre of solution. Reflects charge concentration rather than solute concentration.

Equivalents per Million (epm): Number of moles of solute multiplied by the valence of the solute species in one kilogram of water.

Erratic: Of a rock particle - Is a clast that differs in lithology from the underlying bedrock. Generally applies to ice rafted rocks.

Evapotranspiration (ET): The sum of evaporating plus transpiration. Often related to a particular crop or vegetation group

Facies: A stratigraphic unit distinguished from other units by different appearance or composition.

Falling Head Permeability Tests: Method of determining hydraulic conductivity of the porous medium or geologic formation in the vicinity of a piezometric tip. Based on the time required for the water level in the piezometer to return to static following an artificial increase in head.

Feldspar: A group of abundant rock-forming minerals. See micrococline; orthoclase; plagioclase; anorthoclase.

Feldspathic: Containing feldspar as a principal ingredient.

Felsic: A mnemonic term derived from (fe) for feldspar.

Field Capacity: Of a soil - The moisture content of soil in the field two to three days after a thorough wetting of the soil profile by precipitation or irrigation. (Units: % moisture on a dry weight basis).

on a semi-permanent basis (i.e. not available for plant growth or cannot easily be returned to solution).

Flowing Artesian: Groundwater under sufficient hydrostatic head to rise above ground level, and flow from a well or piezometer.

Flow Line: A line, perpendicular to equipotential lines or surfaces, which represents the direction or groundwater flow in a porous medium.

Flow Net: The set of intersecting equipotential lines and flow lines representing two-dimensional steady flow through porous media.

Flux: The fluid flow across a unit surface area of a porous medium (see Darcy Velocity). ($m^3/s/m^2 = m/s$).

Gneiss: A coarse-grained rock in which bands rich in granular minerals alternate with bands in which schistose minerals predominate.

Granite: A plutonic rock consisting essentially of alkalic feldspar and quartz. Sodic plagioclase, usually oligoclase is commonly present in small amounts and muscovite, biotite, hornblende, or rarely pyroxene, may be mafic constituents.

Groundwater: Subsurface water occurring below the water table in fully saturated geologic materials and formations.

Gyttja: Subaqueous humus form, muddy grey-brown to blackish sediment, rich in organisms occurring in waters sufficiently rich in nutrients and oxygen.

Hardness: Of water - A measure of the amount of calcium, magnesium, and iron dissolved in the water (mg/L).

Heavy Metals: Those metals which have densities greater than 5.0.

Humification: The decomposition of organic matter to form humus.

Humus: The fraction of the soil organic matter that remains after most of the added plant and animal residues have decomposed.

Hydraulic Conductivity (K): Ratio of Darcy velocity to driving hydraulic force (hydraulic gradient) for water, at ambient (i.e. aquifer) temperatures, under saturated conditions (see also Coefficient of Permeability, m/s).

Hydraulic Diffusivity (D): Ratio of hydraulic conductivity (K) to the specific storage (S_s) = $K/S_s = T/S$, (units: m^2/s).

Hydraulic Gradient: Change in hydraulic head per unit length of flow path (dimensionless).

Hydraulic Head: The sum of the pressure and elevation heads (m), demonstrated by the height to which a column of water in a piezometer will rise.

Hydrogeochemical Facies: Groundwater with separate but distinct chemical compositions contained in a hydrogeologic unit.

Hydrogeologic Unit: A formation, part of formation, or a group of formations in which there are similar hydrogeologic characteristics allowing for grouping in aquifers or confining layers. Same as Hydrostratigraphic Unit.

Hydrograph: A graph that shows some property of groundwater or surface water as a function of time.

Hydromorphic: Highly organic (bog or marsh) type of soil.

Hydrostatic Head: Pressure head of water exerted at any given point in a body of stationary water (m).

Hydrostatic Pressure: Pressure exerted by water at any given point in a body of stationary water (kPa).

Hydrostratigraphic Unit: See Hydrogeologic Unit.

Hypsithermal Interval: Postglacial warm interval extending from about 7,000 to 600 B.C., responsible for the last 6-foot eustatic rise of sea level.

Igneous Rocks: Formed by solidification of hot mobile material termed magma.

Illuvial: Of a soil horizon - The B-horizon of the soil profile.

Imbricate: Of a gravel deposit - The shingling or overlapping affect of stream flow upon flat pebbles in the stream bed. The pebbles are inclined so that the upper edge of each individual is inclined in the current direction.

Impermeable: Surface across which there is little or no groundwater flow, relative Boundary to other units.

Infiltration: The flow or movement of water throughout the rock or soil surface into the ground.

Injection Well: A well into which water, gas or liquid waste is injected by gravity flow or under pressure, for the purpose of disposing of waste and/or maintaining formation pressures.

Ion Exchange: A process by which an ion in a mineral lattice is replaced by another ion which was present in an aqueous solution.

Ionic Strength: Constant representing the concentration of ions in solution. Calculated as $I = 1/2\ Mi^2\ Zi^2$. Where:

Mi =	molal concentration of i species
i =	charge of i species
I =	summation for all species

Isopachs: Contour lines, drawn through points of equal thickness of a specified geological unit.

Isopleth: Of a graph or map - A line joining points of equal occurrence or frequency of any phenomenon.

Isostatic: Of a large portion of the earth's crust - Subject to equal pressure from every side, being hydrostatic equilibrium.

Isotropy: Occurs when there is no directional variation of a physical property at a point in a porous media.

Karst: Of a limestone area - Refers to a topographic form, typically a plateau, marked by sink holes, (or karst holes), interspersed with abrupt ridges and irregular protuberant rocks. Usually underlain by caverns and underground streams.

Kinematic Viscosity: The ratio of dynamic viscosity to mass density. It is obtained by dividing dynamic viscosity by the fluid density. Units of kinematic viscosity are square metres per second.

Lagg: Zone where water collects at the margin of a peat land near the mineral ground of the surrounding site. The water in this zone is relatively rich in bases and supports an entrophic type of vegetation.

Laterite: Of a soil - Red residual (illuvial) soil developed in humid tropical regions. It is leached of silica and contains concentrations of iron and aluminum hydroxides.

Leachate: Any fluid percolating through a landfill derived from rain or snowmelt.

Leach: To wash or drain by percolation. To dissolve minerals, chlorine solutions, acids or water.

Leaching Requirement: Of a soil - The amount of water entering the soil that must pass through the root zone in order to prevent the soil salinity from exceeding a specified value. Usually based on steady state or long term conditions. Two methods of determining this parameter are presented in FAO manual no. 24

Leakance: The vertical flux (m/s) through a low hydraulic conductivity confining layer such as a silt or clay bed.

Lineament: Of a surficial topographic or geologic feature - These are significant lines of landscapes which reveal hidden structural aspects of the underlying soil or rock. the lineaments are frequently observed in air photographs and are commonly due to topographic, geologic, soil moisture, vegetation, or drainage pattern anomalies.

Lithification: Of a rock forming process - The process which converts a newly deposited sediment into an indurated rock. Similar to consolidation.

Lithology: Of a rock particle or group of rocks - The physical character of a rock generally as described from a magnifying glass inspection.

Lutite: Sediment or sedimentary rock consisting principally of clay and clay-sized particles.

Lysimeter: A field device containing a soil column with vegetation on the surface, which is used for measuring actual evapotranspiration.

Marl: Loose earthy deposit of calcium or magnesium carbonate, believed to have accumulated in fresh water basins fed by mineral water springs.

Mesic: Refers to a peat material with a high degree of decomposition of organic matter; H7 to H10.

Mesotrophic: Of a lake - In its intermediate stage of aging. This comes between oligotrophic and antrophic. The nutrient content is becoming significant.

Metamorphic Rock: Includes all those rocks which have formed in the solid state in response to pronounced changes of temperature, pressure, and chemical environment, which take place, in general, below the shells of weathering and cementation.

Meteoric Water Line: Line representing the relationship between ^{18}O and ^{2}H precipitation. On a global scale, this line is represented by the equation:

$$^{2}H = 8 \cdot {}^{18}O + 10$$

but can vary from location to location.

Milliquivalents Equivalents Per Litre (meq/L): Equivalents per litre (eq/L) multiplied by 1000. More common expression of charge concentration in dilute solutions.

Molality (m): A measure of chemical concentration. A one-molal solution has one mole of solute dissolved in 1-Kg mass of solution, (mol/kg).

Molarity (M): A measure of chemical concentration. Number of moles of solute in 1 m^3 of solution (mol/L).

Mole (mol): One mole of a compound is the equivalent of one molecular weight (in grams).

Muskeg: North American term frequently employed for peat land.

Oligotrophic: Of a lake - A "young" lake in its earliest stage of antrophication. Characterized by low concentrations of plant and nutrients and little biological productivity.

Ombrotrophic(ous): Nourished by rain only; typically a raised bog. Waters are typically acidic with low calcium and almost no magnesium.

Orogenic: Of the process of forming mountains, particularly by folding and thrusting.

Outlier: Portions of any stratified group rocks which lie detached, or out from the main body. The intervening or connecting portions having been removed by denudation.

Oxidation: Occurs in chemical reaction where electrons are released from an ion or molecule (i.e. oxidation state is increased).

Oxygen-18: Stable isotopes of oxygen (^{18}O) which has two additional neutrons and an atomic weight of 18.

Peat: Unconsolidated soil material consisting largely of undecomposed, or only slightly decomposed, organic matter.

Pedalfer: Soil of humid regions, enriched in alumina and iron. Accumulates in regions of high temperature and humid climate that are marked by forest cover.

Perched Water Table: Saturated soil zone existing within unsaturated soils due to a localized underlying low permeability layer (see Unsaturated Zone).

Percolation: The downward movement under hydrostatic pressure of water through soil.

Periglacial: Of a location - Refers to areas, conditions, processes and deposits adjacent to the margin of a glacier.

Peristaltic Pump: A variable rate low volume pump for groundwater sampling purposes, which excludes sample contamination.

Permeable: Having a texture that permits easy passage of a fluid through the medium (previous).

properties of the porous media (m^2) (see also Coefficient of Permeability).

pH: Negative log of the hydrogen ion activity in solution. $pH = \log (H^+)$.

Phreatophytic: Surface along which the fluid pressure is atmospheric. Same as water table.

Phreatophytic: Of plants - Growing plants that depend on a continuous supply of moisture; normally grow where roots can reach water table.

Piezometer: A device used to measure the pressure or pressure head in a short sealed off length of a drillhole or hydrogeologic unit. The device normally measures a fluid level in a small diameter tube, or a water pressure.

Piezometer Nest: A set of two or more piezometers set close to each other but screened at different depths.

Piezometric Level: The level to which the water rises in an open standpipe piezometer. Water level is either measured relative to ground surface, an assumed datum or given as an elevation.

Piezometric Surface: Imaginary surface defined by piezometric levels in a specified hydrogeologic unit.

Pluton: A body of igneous rock that has formed beneath the surface of the earth by consolidation from magma.

Porosity (n): Proportion of the total volume of a porous medium occupied by voids (dimensionless fraction).

Pressure Head: Fluid pressure divided by unit weight of water (m).

Pseudo Stratification: Of unconsolidated rock materials: Layers of material which are not stratified by the normal sorting process, but by other mechanical means, e.g. hill deposits overridden by ice, drumlins, etc.

Quartz: A mineral, $Si0_2$. Hexagonal, trigonal-trapezohedral.

Raised Bog: Raised muskeg, domed bog, high bog, raised peat land, ombrotrophic bog (rain fed).

Recharge Area: An area in which the hydraulic gradient has a downward component. infiltration moves downward in the deeper parts of an aquifer in a recharge area.

Recharge Boundary: Surface across which there is a nearly constant hydraulic head. Rivers, lakes, and other bodies of surface water often form recharge boundaries.

Recharge Well: A well through which good quality water is allowed to flow or is injected under pressure into one or more aquifers for the purpose of supplementing or conserving fresh water supplies, reducing water table decline or reducing potential for salt water intrusion.

Redox Potential: Same as Eh.

Redox Process: Every oxidation reaction is accompanied by a reduction reaction and vice versa, so that an electron balance is always maintained.

Reduction: Occurs in a chemical reaction where electrons are gained by an ion or molecule (i.e. oxidation state is decreased).

Regressive: Apposite to transgressive.

Reticulate: Of rocks - Having a "honeycomb" appearance.

Return Well: Well through which water from a particular aquifer that has been withdrawn for heating or cooling purposes is returned. Water quality should be essentially unchanged.

Runoff: The portion of the total precipitation on an area that flows away through stream channels.

Saporite: A residual clay - silt soil (eluvium), with traces of minerals, such as iron. Is commonly a red brown colour. Laterite soils are a special type of saporite, with dominant silica and traces of iron and aluminium hydroxides (bauxite).

Saturated Zone: The zone of a porous medium in which all the voids are completely filled with water.

Sedimentary Rocks: Rocks formed by the accumulation of sediment in water (aqueous deposits) or from air (eoilian deposits). The sediment may consist of rock fragments or particles of various sizes (conglomerate, sandstone, shale); of the remains or products of animals or plants (certain limestones and coal); of the product of chemical action or of evaporation (salt, gypsum, etc.); or of mixtures of these materials. Some sedimentary deposits (tuffs) are composed of fragments blown from volcanoes and deposited on land or in water. A characteristic feature of sedimentary deposits is a layered structure known as bedding or stratification. Each layer is a bed or stratum. Sedimentary beds as deposited lie flat or nearly flat.

Slickenside: Scratches and grooves produced by movement along fault planes.

SNOW: Standard Mean Ocean Water. The internationally accepted standard for referencing analyzed ^{18}O and ^{2}H isotope contents.

Sodium Adsorption Ratio (SAR): Of a soil - The ratio of soil extracts and irrigation waters used to express the relative activity of Na^+ in exchange with soil.

$$SAR = \frac{Na^+}{0.5\ [Ca^{+2} + Mg^{+2}]^{1/2}}$$

Expressed as meq/L

Soil: That earth material which has been so modified and acted upon by physical, chemical and biological agents that it will support rooted plants (i.e. pedological definition of soil).

Soligenous (ic): Produced from soil; refers to peat land deposit that is nourished by mineral water from higher surroundings.

Soluble Sodium Percentage (SSP): Of a water - Indicates the proportion of Na^+ in solution in either irrigation water or soil extract) to total cation concentration.

$$SSP = \frac{Na^+ \times 100}{[\text{Total Cations}]} \quad (\%)$$

Solum: Of a soil - The upper part of a soil profile consisting of the A and B horizons.

Solute: That constituent of a solution which is considered to be dissolved in the other, the solvent.

Solvent: That constituent of a solution which is present in larger amount (i.e. water).

Specific Capacity (Sc): Term describing the productivity of a well. Calculated as the pumping rate divided by drawdown at a selected time after pumping is started (L/s/m).

Specific Surface: Of a soil particle: Surface area per unit weight of soil (Unit = m^2/gm).

Specific Storativity (Ss): Volume of water that is released from a unit volume of an elastic hydrogeologic unit, with a compressible fluid, under a unit decline of hydraulic head (L/m).

Specific Yield (Sy): Volume of water that an unconfined aquifer released from storage, per unit surface area of aquifer per unit decline in the water table (dimensionless). Same as storativity for unconfined non-elastic aquifers with incompressible fluid.

Spring: A place where water flows from a rock or soil onto the land or in a body of water, without the agency of man being involved.

Static Water Level: Level at which water stands in a piezometer or well set in an aquifer which is not being pumped.

Steady-State Flow: Fluid movement that is not time dependent.

Stream: Any body of flowing water or other fluid, great or small.

Sump: A hole or pit which serves for the collection of quarry or mine waters.

Synchronal: Occurring at the same time.

TDS: Total dissolved solids in a solution (mg/L).

Tensionmeter: A device used to measure the soil moisture tension in the unsaturated zone.

Through Flow: Groundwater that flows rapidly through a highly permeable near surface zone during intense rainfall events.

Till: Of a sedimentary deposit - unsorted, non stratified sediment carried or deposited by a glacier.

T.U.: See Tritium Unit

Transgressive: Of a deposited formation overlap; due to an advance of deposition over lower layers. Marine deposition at an advancing coastline is transgressive.

Transient Flow: See Unsteady-State Flow.

Transmissivity (T): Rate of horizontal water flow in cubic metres per second through a vertical strip of aquifer one metre wide, and extending the full saturated thickness of the aquifer, under a hydraulic gradient of one metre per metre at the prevailing water temperature (m^2/s).

Tritium: Radioactive isotope of hydrogen (^1H). Tritium (^3H) has a half life of 12.35 years. Natural levels in the hydrosphere are between 5 and 20 tritium units T.U.

Tritium Unit (T.U.): Unit for expressing Tritium concentrations in water. 1 T.U. = 1 $^3H/10^{18}$ ^1H.

Unconformity: A surface of erosion or no deposition, usually the former, that separates younger strata from older rocks.

Uniformity Coefficient: Defines variation in grain size of granular material. Ratio of D_{60}/D_{10} size = (D_{60} = sieve size through which 60% will pass).

Unsaturated Zone: The zone between the land surface and the water table. It includes the root zone, intermediate zone, and capillary fringe. The pore spaces contain water at less than atmospheric pressure, as well as air and other gases. Saturated zones, such as perched groundwater, may exist in the unsaturated zone.

Unsteady-State Flow: Fluid movement that is time dependent (i.e. transient flow).

Valence: The charge, whether positive or negative carried by an ion in an aqueous solution i.e. valence of Cl^- = 1; Ca^{2+} = 2.

Water Table: Surface along which the fluid pressure is atmospheric, and below which the fluid pressure is greater than atmospheric (i.e. top of saturated zone).

Well: Shaft sunk in ground and lined with stone or other protection for obtaining subterranean water, oil, etc.

SYMBOLS

o/oo : Per mil. unit. Used for expressing environmental isotope content. One per mil. is one unit per thousand units. (See ^{18}O $^o/_{oo}$ and ^2H $^o/_{oo}$ below).

^{2}H : Expression of the deuterium content of a water sample relative to Standard Mean Ocean Water (SMOW) where:

$$\delta^2H\ ^o/_{oo} = \frac{[^2H/^1H]_{sample} - [^2H/^1H]_{SMOW}}{[^2H/^1H]_{SMOW}} \times 1{,}000$$

^{18}O : Expression of the oxygen-18 content of a water sample relative to Standard Mean Ocean Water (SMOW) where:

$$\delta^{18}O\ ^o/_{oo} = \frac{[^{18}O/^{16}O]_{sample} - [^{18}O/^{16}O]_{SMOW}}{[^{18}O/^{16}O]_{SMOW}} \times 1{,}000$$

^{14}C : Amount of radioactive carbon-14 (^{14}C) in a sample of organic material, CO_2 gas, dissolved carbonate or in carbonate minerals. Expressed as a percent of modern carbon-14 levels. Older samples will have less carbon-14 due to natural radioactive decay. (Unit = pmC)

APPENDIX B

DRAFT REGULATION FOR GROUNDWATER MANAGEMENT

APPENDIX B

PROPOSED GROUNDWATER REGULATIONS

As indicated in Section 8.3 of this report, a new draft water control legislation was finalized in 1990 by a Government of Swaziland steering committee, with the assistance of CIDA's executing agency (PAEL, 199). If accepted, this legislation will make it clear that unconditional riparian rights will be abolished and that a new National Water Authority (NWA) will be responsible for setting water sector policy and ensuring that such policy is carried out.

It is anticipated that the NWA will delegate issuance of both surface and groundwater use permits to the Water Apportionment Board (the Board). It is anticipated that the Board will in turn, will likely delegate the day to day management of the groundwater resource to the recently expanded Groundwater Section of the Department of Geological Surveys and Mines (DGSM).

Under the legislation, permits will be required from the DGSM before boreholes are drilled and high rates of groundwater abstraction is allowed. Permittees will also be required to submit data on boreholes and yields to the DGSM. Because water quality is also important, the draft also provides for the control of pollution by the requirement for a permit to discharge wastes onto the ground surface.

The text of draft regulation (No. 2), relating to permitting groundwater use in Swaziland is presented in the following.

1. Every applicant for a permit to drill a borehole or well, or to expand an existing borehole or to increase the capacity of any equipment used to extract water from a borehole shall prepare and sign an application form in the approved form giving the following particulars:

a) The applicant's name, address and occupation;

b) A description of the location of the proposed or existing borehole;

c) The proposed diameter and depth of the proposed borehole or expanded borehole;

d) The type and capacity of the proposed equipment to be used to extract water from the proposed or expanded or existing borehole;

e) The diameter and depth of the existing borehole and the type and capacity of equipment used to extract water from the existing borehole (if applicable);

f) The purpose for which the water is used or is to be used;

g) A description of the lands upon which the water is used or is to be used;

h) The maximum quantity of water to be used, if found available, and the period or periods of such use;

i) The name and address of the person, agency or company who will construct the borehole or the expanded borehole or who will install the larger capacity equipment.

2. The application shall contain a statement that any person who considers that his interests may be adversely affected by the granting of the permit applied for may file an objection with the Board within 30 days.

3. The application shall contain an undertaking by the applicant to require the person constructing the borehole or expanded borehole to maintain adequate records and logs of the work and to furnish the same to the Board upon completion of the work.

4. The applicant shall post a signed copy of the application at the site of the proposed or existing borehole as the case may be.

5. The applicant shall within 14 days of posting the application at the site of the

proposed or existing borehole file three signed copies with the Board.

6. The applicant shall provide the Board with any information it may require relating to the application or to the availability or anticipated availability of water or the proposed use of the water or to any works or equipment which may be proposed or equipment which may be used in constructing the borehole or expanded borehole.

7. The applicant shall pay the Board with his application such fee as may be prescribed by regulation.

8. Any person who considers that his interests may be adversely affected by the granting of the permit applied for may file an objection with the Board.

9. Such objection shall be in writing, shall be signed and shall be delivered to the Board within 30 days of posting the application at the site of the proposed or existing borehole.

10. The objection shall set out the grounds for such objection.

11. A copy of the objection shall be delivered forthwith by the objector to the applicant.

12. An application or an objection may be signed and posted and filed by a duly authorized agent of the applicant or the objector.

13. The Board will consider the application and any objections filed and will decide whether the application or objections warrant the holding of a public hearing. If the Board decides not to hold a public hearing, it will send written notice to any objectors of its decision. The decision of the Board shall be final.

14. If a public hearing has not been held, the Board will give objectors not less than twenty-one days notice of the time and place at which the Board will meet to decide on the application. The objectors shall be provided full opportunity to present their objections to the Board, in person and with witnesses, at such meeting or any adjournment thereof.

15. The Board will give written notice to the applicant and to any objectors of its decision with regard to the application.

16. The Board may issue a permit subject to such conditions as it deems advisable. Without limiting the generality of the foregoing, the Board may issue a permit conditional upon the Board or its authorized agent approving the person who will construct the borehole or expanded borehole to ensure that the Board receives proper records of the subsurface conditions.

APPENDIX C

CLIMATE DATA

TABLE: C1

SUMMARY OF RAINFALL DATA FOR SELECTED[1] SWAZILAND CLIMATE STATIONS

STATION	ELEV[2] (m-asl)	MONTHLY AVERAGE (mm)												ANNUAL AVG (mm)
		JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	
BIG BEND	155.0	93	68	59	37	22	14	11	9	30	49	80	85	557.0
BULEMBU	1,167.0	294.7	263.7	192.8	103.7	44.2	25.4	27.5	37.2	79.8	153.4	212.2	254.7	1,689.3
FOYER'S	381.0	121.5	111.8	85.6	57.7	30.9	15.8	12.3	13.6	39.8	80.9	113.4	128.8	812.1
LAVUMISA	135.0	83.90	80.10	54.10	41.30	23.30	13.10	10.90	14.90	31.00	55.00	81.30	88.40	577.1
MANANGA (VUVULANE)	300.0	138.7	131.4	92.8	63.9	29.4	15.3	15.4	13.8	38.5	70.9	104.3	124.6	839.0
MANKAYANE	1,009.0	147.4	123.0	105.7	53.8	24.6	12.5	15.0	13.3	42.8	88.0	129.5	130.6	886.2
MATSAPHA (MANZINI)	610.0	163.6	135.1	106.7	58.1	25.7	14.4	13.8	18.7	42.9	80.5	120.7	136.2	916.5
MBABANE	1,145.0	252.1	212.2	171.3	79.1	34.2	18.4	21.6	29.3	63.7	126.6	179.0	212.9	1,400.4
NHLANGANO	1,036.0	125.1	124.9	87.4	63.0	25.2	14.3	13.0	15.7	45.0	82.0	125.4	127.8	848.9
SIPHOFANENI	365.0	106.0	96.4	78.2	59.3	22.7	16.0	14.9	15.8	27.9	54.0	78.4	94.5	664.1
SITEKI	653.0	136.8	129.3	108.8	56.8	28.5	16.6	15.9	20.2	40.7	74.3	98.5	119.9	846.3
Minimum	135.0	83.9	68.0	54.1	37.0	22.0	12.5	10.9	9.0	27.9	49.0	78.4	85.0	557.0
Average	632.4	151.2	134.2	103.9	61.2	28.2	16.0	15.6	18.3	43.8	83.1	120.2	136.7	912.4
Maximum	1,167.0	294.7	263.7	192.8	103.7	44.2	25.4	27.5	37.2	79.8	153.4	212.2	254.7	1,689.3

NOTES: 1. For more detailed information regarding individual stations see station summaries in Appendix C

2. Elevation of substitute rainfall station presented (as named in brackets) where appropriate.

SUMMARY OF TEMPERATURE DATA FOR SELECTED[1] SWAZILAND CLIMATE STATIONS

STATION	ELEV[2] (m-asl)	MONTHLY AVERAGE (°C)												ANNUAL AVG (mm)
		JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	
BIG BEND	155.0	27.6	25.9	25.6	22.9	18.5	16.5	16.3	19.3	22.5	24.6	25.0	26.7	22.6
BULEMBU	1,167.0	20.0	19.9	19.2	17.7	15.3	12.9	13.2	14.7	16.5	17.4	18.5	19.6	17.0
LAVUMISA	135.0	26.5	24.2	24.1	21.8	19.9	17.6	16.8	18.6	20.2	21.0	23.0	23.4	21.4
MANANGA	230.0	25.9	25.3	24.3	22.2	19.6	16.9	17.5	19.4	21.5	22.0	23.6	25.3	21.9
MATSAPHA	642.0	23.6	23.1	22.5	20.2	18.0	15.3	15.8	16.9	19.2	20.0	21.2	22.8	19.9
MBABANE	1,145.0	20.0	19.8	18.8	17.1	14.5	12.1	12.4	14.2	16.2	17.6	18.5	19.6	16.7
NHLANGANO	1,036.0	20.8	20.9	20.2	19.5	15.6	13.5	14.5	15.6	17.1	18.2	18.9	20.3	17.9
SITEKI	653.0	22.6	22.2	22.4	20.0	18.1	15.9	15.7	17.3	18.2	19.6	20.4	22.1	19.5
Minimum	135.0	20.0	19.8	18.8	17.1	14.5	12.1	12.4	14.2	16.2	17.4	18.5	19.6	16.7
Average	645.4	23.4	22.6	22.1	20.2	17.4	15.0	15.3	17.0	18.9	20.0	21.1	22.4	19.6
Maximum	1,167.0	27.6	25.9	25.6	22.9	19.9	17.6	17.5	19.4	22.5	24.6	25.0	26.7	22.6

NOTES: 1. For more detailed information regarding individual stations see station summaries in Appendix C

TABLE: C2

STATION NAME:	MONTH	PRECIPITATION (mm) for 1952 to 1972						
		RAINFALL			RAIN-DAYS			MAX-24
FOYER'S		MAX	MEAN	MIN	MAX	MEAN	MIN	HR RAIN
ID No: 483/72	OCT	150.0	80.9	80.9	19	9	5	52.0
Map No: 17	NOV	244.4	113.4	113.4	16	11	5	89.7
	DEC	327.0	128.8	128.8	21	10	5	104.0
LAT : 26° 12' S	JAN	311.0	121.5	121.5	18	9	5	85.5
LONG : 31° 32' E	FEB	281.0	111.8	111.8	16	8	2	100.0
ELEV : 381 M	MAR	241.0	85.6	85.6	18	7	2	104.9
	APR	163.0	57.7	57.7	11	6	0	81.0
RECORD (yrs):	MAY	96.5	30.9	30.9	11	4	0	66.8
Precip: 20	JUN	96.5	15.8	15.8	5	2	0	55.0
	JUL	56.1	12.3	12.3	7	2	0	43.0
	AUG	68.5	13.6	13.6	6	2	0	53.5
	SEP	142.2	39.8	39.8	9	4	0	63.9
MONTH STATS		327.0	67.7	12.3	21	6	0	104.9
(Year)		1960			1960			1953
ANNUAL		1221.7	812.1	446.8	123	74	46	
(Year)		1971-72		1963-64	1971-72		1963-64	

STATION NAME:	MONTH	PRECIPITATION (mm) for 1929 to 1973							TEMPERATURE (° C) for 1951 to 1986				
		RAINFALL			RAIN-DAYS			MAX-24	ABS	AVE	MEAN	AVE	ABS
LAVUMISA		MAX	MEAN	MIN	MAX	MEAN	MIN	HR RAIN	MAX	MAX		MIN	MIN
ID No: 410/709	OCT	168.3	55.00	0.0	12	5	0	67.3	44.2	27.2	21.0	14.7	2.5
Map No: 63	NOV	246.4	81.30	0.0	14	7	0	84.0	42.2	29.4	23.0	16.5	3.0
	DEC	257.3	88.40	8.0	14	6	2	101.9	44.0	29.9	23.4	16.9	0.5
LAT : 27° 19 S	JAN	284.9	83.90	3.0	12	6	1	85.5	47.4	34.1	26.5	18.9	6.5
LONG : 31° 54 E	FEB	283.0	80.10	2.3	15	6	0	84.0	42.0	31.1	24.2	17.3	6.4
ELEV : 135 M	MAR	168.0	54.10	0.0	10	5	0	82.5	45.0	30.6	24.1	17.5	7.0
	APR	126.0	41.30	0.0	9	4	0	48.3	40.0	28.4	21.8	15.1	3.6
RECORD (yrs):	MAY	98.5	23.30	0.0	8	2	0	86.5	39.2	27.7	19.9	12.1	4.0
Precip: 44	JUN	112.5	13.10	0.0	5	1	0	90.2	38.4	25.9	17.6	9.2	0.1
Temp: 35	JUL	86.1	10.90	0.0	6	1	0	55.4	38.5	24.5	16.8	9.0	0.1
	AUG	116.3	14.90	0.0	4	1	0	57.1	40.5	26.3	18.6	10.8	-0.5
	SEP	169.9	31.00	0.0	12	3	0	46.2	43.2	27.1	20.2	13.3	4.5
MONTH STATS		284.9	48.1	0.0	15	3.9	0	101.9	47.4	28.5	21.4	14.3	-0.5
(Year)		1951			1956			1939					
ANNUAL		951.2	577.1	318.4	81	47	31						
(Year)		1939-40		1930-31	1955-56		1961-62						

TABLE: C3

STATION NAME:	MONTH	PRECIPITATION[1] (mm) for 1922 to 1975							TEMPERATURE (°C):1965 to 1984					PAN EVAPORATION (mm):1972 to 1989		
		RAINFALL			RAIN-DAYS			MAX-24	ABS	AVE	MEAN	AVE	ABS			
MANANGA (VUVULANE)		MAX	MEAN	MIN	MAX	MEAN	MIN	HR RAIN	MAX	MAX		MIN	MIN	MAX	MEAN	MIN
ID No: (483/695)	OCT	228.2	70.9	19.6	13	6	3	83.0	38.3	27.1	22.0	16.9	11.9	254.2	208.4	139.5
Map No: 13 (22)	NOV	296.1	104.3	2.8	15	8	1	119.5	39.0	28.8	23.6	18.4	14.6	249.0	201.0	135.0
	DEC	297.1	124.6	11.2	15	8	2	104.5	39.7	30.4	25.3	20.1	17.2	319.3	243.0	186.0
LAT : 26° 00' S	JAN	426.2	138.7	3.3	18	8	2	170.0	42.6	30.7	25.9	21.0	11.8	347.2	230.1	170.5
LONG : 31° 45' E	FEB	444.5	131.4	3.0	13	7	1	139.7	39.6	29.9	25.3	20.6	15.2	252.3	198.7	162.4
ELEV : 230 (300)	MAR	250.3	92.8	0.0	17	7	0	95.0	35.4	29.3	24.3	19.3	14.5	223.2	173.6	49.6
	APR	158.3	63.9	0.0	10	5	0	79.0	35.7	27.5	22.2	16.8	8.2	201.0	144.2	117.0
RECORD (yrs):	MAY	167.9	29.4	0.0	8	2	0	68.0	35.4	25.9	19.6	13.2	7.7	151.9	128.6	96.1
Precip: 53	JUN	102.2	15.3	0.0	10	2	0	38.0	30.2	24.0	16.9	9.7	5.4	141.0	114.2	90.0
Temp: 20	JUL	83.0	15.4	0.0	6	2	0	58.0	35.5	24.5	17.5	10.4	3.0	182.9	139.1	105.4
Evap: 18	AUG	82.3	13.8	0.0	9	2	0	43.2	34.0	26.1	19.4	12.6	5.9	192.2	171.0	130.2
	SEP	223.2	38.5	0.0	11	3	0	95.0	39.2	27.6	21.5	15.4	8.5	282.0	196.1	123.0
MONTHLY TOTAL		444.5	69.9	0.0	18	5.0	0	170.0	42.6	27.7	21.9	16.2	3.0	347.2	179.0	49.6
(Year)		1977			1978			1966						1983		1984
ANNUAL TOTAL		1522.2	839.0	330.7	85	60	33									
(Year)		1971–72		1963–64	1977–78		1963–64									

NOTE: 1. Precipitation data from Vuvulane station was used.

STATION NAME:	MONTH	PRECIPITATION (mm) for 1909 to 1978						
		RAINFALL			RAIN-DAYS			MAX-24
MANKAYANE		MAX	MEAN	MIN	MAX	MEAN	MIN	HR RAIN
ID No: 445/100	OCT	257.0	88.0	9.9	19	9	2	63.6
Map No: 49	NOV	277.6	129.5	28.2	23	11	3	91.4
	DEC	279.9	130.6	30.7	19	11	2	91.4
LAT : 26° 40' S	JAN	506.0	147.4	5.0	20	11	1	220.7
LONG : 31° 04' E	FEB	333.5	123.0	14.0	18	9	2	134.9
ELEV : 1009 M	MAR	350.5	105.7	2.5	24	9	2	93.0
	APR	185.9	53.8	0.0	14	5	0	57.5
RECORD (yrs):	MAY	111.8	24.6	0.0	12	3	0	48.0
Precip: 69	JUN	147.4	12.5	0.0	8	2	0	67.7
	JUL	113.5	15.0	0.0	9	2	0	66.8
	AUG	104.6	13.3	0.0	10	2	0	53.3
	SEP	136.1	42.8	0.0	13	5	0	63.5
MONTH STATS		506.0	73.9	0.0	24	7	0	220.7
(Year)		1918			1925			1918
ANNUAL		1734.1	886.2	391.5	122	79	33	
(Year)		1917–18		1964–65	1916–17		1964–65	

TABLE: C4

STATION NAME: SIPHOFANENI	MONTH	PRECIPITATION (mm) for 1935 to 1978 RAINFALL MAX	RAINFALL MEAN	RAINFALL MIN	RAIN-DAYS MAX	RAIN-DAYS MEAN	RAIN-DAYS MIN	MAX-24 HR RAIN
ID No: 446/311	OCT	152.1	54.0	0.0	14	6	0	49.0
Map No: 52	NOV	190.0	78.4	8.0	13	7	1	60.0
	DEC	334.3	94.5	25.4	13	7	2	120.0
LAT : 26° 41' S	JAN	449.6	106.0	16.5	15	6	1	99.0
LONG : 31° 41' E	FEB	421.6	96.4	5.5	13	6	1	88.5
ELEV : 365 M	MAR	243.0	78.2	0.0	12	6	0	136.0
	APR	186.9	59.3	0.0	14	5	0	98.0
RECORD (yrs):	MAY	101.0	22.7	0.0	6	2	0	29.5
Precip: 43	JUN	107.5	16.0	0.0	5	1	0	45.0
	JUL	119.4	14.9	0.0	6	2	0	34.0
	AUG	175.5	15.8	0.0	5	2	0	22.0
	SEP	121.5	27.9	0.0	11	3	0	56.0
MONTH STATS		449.6	55.3	0.0	15	4	0	136.0
(Year)		1978			1935			1968
ANNUAL		1199.9	664.1	402.3	98	53	29	
(Year)		1938-39		1951-52	1938-39		1963-64	

STATION NAME: NHLANGANO	MONTH	PRECIPITATION (mm) for 1934 to 1978 RAINFALL MAX	RAINFALL MEAN	RAINFALL MIN	RAIN-DAYS MAX	RAIN-DAYS AVE	RAIN-DAYS MIN	MAX-24 HR RAIN	TEMPERATURE (° C) for 1955 to 1986 ABS MAX	AVE MAX	MEAN	AVE MIN	ABS MIN
ID No: 409/337	OCT	234.6	82.0	15.7	21	11	2	127.0	36.1	24.3	18.2	12.1	1.3
Map No: 71	NOV	292.6	125.4	18.8	21	12	4	74.9	38.4	23.9	18.9	13.8	6.5
	DEC	331.0	127.8	33.5	23	12	4	93.0	39.0	25.5	20.3	15.0	6.5
LAT : 27° 07 S	JAN	347.0	125.1	23.9	22	12	4	79.2	35.5	25.6	20.8	15.9	7.2
LONG : 31° 02 E	FEB	281.3	124.9	21.3	19	11	4	96.0	35.3	26.0	20.9	15.8	9.4
ELEV : 1036 m	MAR	237.5	87.4	16.0	17	9	1	129.0	37.5	25.6	20.2	14.7	5.5
	APR	182.6	63.0	6.1	12	7	1	72.5	33.0	23.8	19.5	15.2	3.0
RECORD (yrs):	MAY	95.3	25.2	0.0	13	3	0	48.0	32.0	22.1	15.6	9.0	2.3
Precip: 44	JUN	126.6	14.3	0.0	8	2	0	56.0	28.8	20.6	13.5	6.3	-5.4
Temp: 29	JUL	126.0	13.0	0.0	8	2	0	55.0	32.7	22.6	14.5	6.4	-5.4
	AUG	95.0	15.7	0.0	8	3	0	34.3	36.4	22.7	15.6	8.5	-4.5
	SEP	174.0	45.0	0.0	15	6	0	65.0	36.1	23.3	17.1	10.8	-2.0
MONTH STATS		347.0	70.7	0.0	23	8	0	129.0	39.0	22.6	17.9	10.8	-5.4
(Year)	1946							1946					
ANNUAL	1218.0		848.9	573.1	123	89	20						
(Year)	1960-61			1951-52	1946-47		1977-78						

TABLE: C5

STATION NAME: SITEKI	MONTH	PRECIPITATION (mm) for 1899 to 1978 — RAINFALL MAX	MEAN	MIN	RAIN-DAYS MAX	MEAN	MIN	MAX-24 HR RAIN	TEMPERATURE (° C) for 1926 to 1976 — ABS MAX	AVE MAX	MEAN	AVE MIN	ABS MIN
ID No: 483/807	OCT	222.3	74.3	4.3	19	8	1	66.5	38.2	25.3	19.6	13.8	5.0
Map No: 44	NOV	253.7	98.5	14.7	17	9	2	83.3	37.8	25.8	20.4	14.9	6.0
	DEC	318.0	119.9	16.6	20	10	3	119.0	36.7	27.9	22.1	16.2	6.1
LAT : 26° 27' S	JAN	501.1	136.8	0.0	26	10	0	150.0	37.8	27.5	22.6	17.7	10.0
LONG : 31° 57' E	FEB	439.4	129.3	7.0	19	9	1	209.0	36.1	27.3	22.2	17.1	8.5
ELEV : 653 M	MAR	678.4	108.8	0.0	24	9	0	120.7	37.0	27.9	22.4	16.9	10.0
	APR	253.7	56.8	0.0	18	6	0	73.7	33.9	25.0	20.0	15.0	7.8
RECORD (yrs):	MAY	202.4	28.5	0.0	18	4	0	82.8	32.5	23.4	18.1	12.8	5.0
Precip: 80	JUN	149.1	16.6	0.0	13	3	0	149.1	31.0	21.3	15.9	10.4	0.1
Temp: 50	JUL	115.8	15.9	0.0	11	3	0	65.0	30.0	21.2	15.7	10.1	2.4
	AUG	145.0	20.2	0.0	18	2	0	96.0	35.0	23.1	17.3	11.5	5.2
	SEP	213.1	40.7	0.0	21	5	0	141.0	41.4	24.1	18.2	12.3	5.0
MONTH STATS		678.4	73.2	0.0	26	6.5	0	209.0	41.4	25.0	19.5	14.1	0.1
(Year)		1925			1918			1918					
ANNUAL		1608.8	846.3	390.0	69	78	34						
(Year)		1917-18		1930-31	1917-18		1969-70						

TABLE: C6

STATION NAME: MBABANE	MONTH	PRECIPITATION (mm) for 1903 to 1981 RAINFALL MAX	RAINFALL MEAN	RAINFALL MIN	RAIN-DAYS MAX	RAIN-DAYS MEAN	RAIN-DAYS MIN	MAX-24 HR RAIN	TEMPERATURE (° C):1926 to 1986 ABS MAX	AVE MAX	MEAN	AVE MIN	ABS MIN	PAN EVAPORATION (mm):1968 to 1988 MAX	MEAN	MIN
ID No: 482/260	OCT	358.4	126.6	23.4	24	14	5	99.5	35.6	23.3	17.6	11.8	-1.0	164.3	131.4	55.8
Map No: 29	NOV	329.7	179.0	61.5	26	17	8	83.0	35.6	23.7	18.5	13.2	4.4	174.0	125.8	90.0
	DEC	427.6	212.9	62.6	27	17	5	134.2	37.2	24.7	19.6	14.5	5.3	182.9	129.7	37.2
LAT : 26° 20' S	JAN	644.9	252.1	58.7	26	17	5	212.1	34.0	24.9	20.0	15.1	6.2	179.8	134.5	65.1
LONG : 31° 09' E	FEB	629.9	212.2	55.1	22	15	6	208.3	35.0	24.6	19.8	14.9	6.4	156.6	118.6	56.0
ELEV : 1145 M	MAR	861.6	171.3	34.9	27	14	4	133.1	33.5	23.7	18.8	13.9	4.4	145.7	111.8	62.0
	APR	339.1	79.1	6.0	23	10	1	74.7	33.3	22.7	17.1	11.4	-3.0	129.0	94.2	48.0
RECORD (yrs):	MAY	153.2	34.2	0.0	15	5	0	81.0	30.4	21.0	14.5	8.0	-1.3	117.8	84.8	52.1
Precip: 78	JUN	135.5	18.4	0.0	9	3	0	110.0	29.4	19.1	12.1	5.0	-4.5	99.0	75.3	54.0
Temp: 40	JUL	120.5	21.6	0.0	12	3	0	66.0	28.5	19.4	12.4	5.4	-6.1	108.5	85.4	43.4
Evap: 21	AUG	153.9	29.3	0.0	17	5	0	67.3	35.2	21.3	14.2	7.0	-5.0	155.0	113.6	74.4
	SEP	198.5	63.7	3.8	20	8	1	68.3	27.2	22.7	16.2	9.6	-2.2	159.0	123.2	33.0
MONTHLY TOTAL		861.6	116.7	0.0	27	11	0	212.1	37.2	22.6	16.7	10.8	-6.1	182.9	110.7	33.0
(Year)		1925			1937			1953						1986		1979
ANNUAL TOTAL		2563.8	1400.4	901.5	169	128	67									
(Year)		1924-25		1963-64	1942-43		1962-63									

STATION NAME: MATSAPHA (MANZINI)	MONTH	PRECIPITATION[1] (mm) for 1897 to 1978 RAINFALL MAX	RAINFALL MEAN	RAINFALL MIN	RAIN-DAYS MAX	RAIN-DAYS MEAN	RAIN-DAYS MIN	MAX-24 HR RAIN	TEMPERATURE (°C):1965 to 1984 ABS MAX	AVE MAX	MEAN	AVE MIN	ABS MIN	PAN EVAPORATION (mm): 1976 to 1987 MAX	MEAN	MIN
ID No: 482/689	OCT	227.2	80.5	5.1	19	10	3	111.0	40.5	25.5	20.0	14.5	8.0	201.5	151.4	102.3
Map No: 41 (42)	NOV	292.9	120.7	25.7	19	12	4	111.0	38.0	26.4	21.2	16.0	9.5	258.0	168.8	102.0
	DEC	289.0	136.2	28.4	23	12	2	246.2	37.5	28.0	22.8	17.5	4.5	244.9	175.2	117.8
LAT : 26° 32' S	JAN	471.7	163.6	10.4	23	12	5	190.5	40.0	28.6	23.6	18.6	11.0	213.9	166.3	102.3
LONG : 31° 10' E	FEB	341.4	135.1	20.4	18	11	4	139.7	38.2	27.9	23.1	18.3	12.9	170.8	141.5	75.4
ELEV : 642 M(Lto)	MAR	471.2	106.7	21.1	20	10	3	135.4	38.5	27.4	22.5	17.6	11.5	170.5	140.7	103.6
	APR	252.0	58.1	0.0	13	6	0	96.5	36.5	25.5	20.2	14.9	7.6	138.0	124.0	99.0
RECORD (yrs):	MAY	158.0	25.7	0.0	11	4	0	64.8	34.0	24.3	18.0	11.7	5.1	148.8	125.6	96.1
Precip: 81	JUN	130.0	14.4	0.0	7	2	0	116.1	30.1	22.2	15.3	8.4	2.5	180.0	121.0	99.0
Temp: 17	JUL	136.4	13.8	0.0	10	2	0	114.8	32.5	22.5	15.8	9.0	2.0	151.9	118.1	89.9
Evap: 22	AUG	147.6	18.7	0.0	9	2	0	71.4	36.5	24.0	16.9	9.8	2.6	158.1	130.7	89.9
	SEP	188.4	42.9	0.0	14	5	0	68.5	36.5	25.3	19.2	13.0	3.0	189.0	147.8	117.0
MONTH STATS		471.7	76.4	0.0	23	7	0	246.2	40.5	25.6	19.9	14.1	2.0	258.0	142.6	75.4
(Year)		1915			1935			1976						1983[2]		1981
ANNUAL		1493.3	916.5	0.0	135	87	0									
(Year)		1926-27		1926-27	1971-72		1977-78									

NOTES: 1. Precipitation data from Manzini station was used.
2. Based on limited data (15 days).

TABLE: C7

NOTES: 1. Precipitation data from Manzini station was used.
2. Based on limited data (15 days).

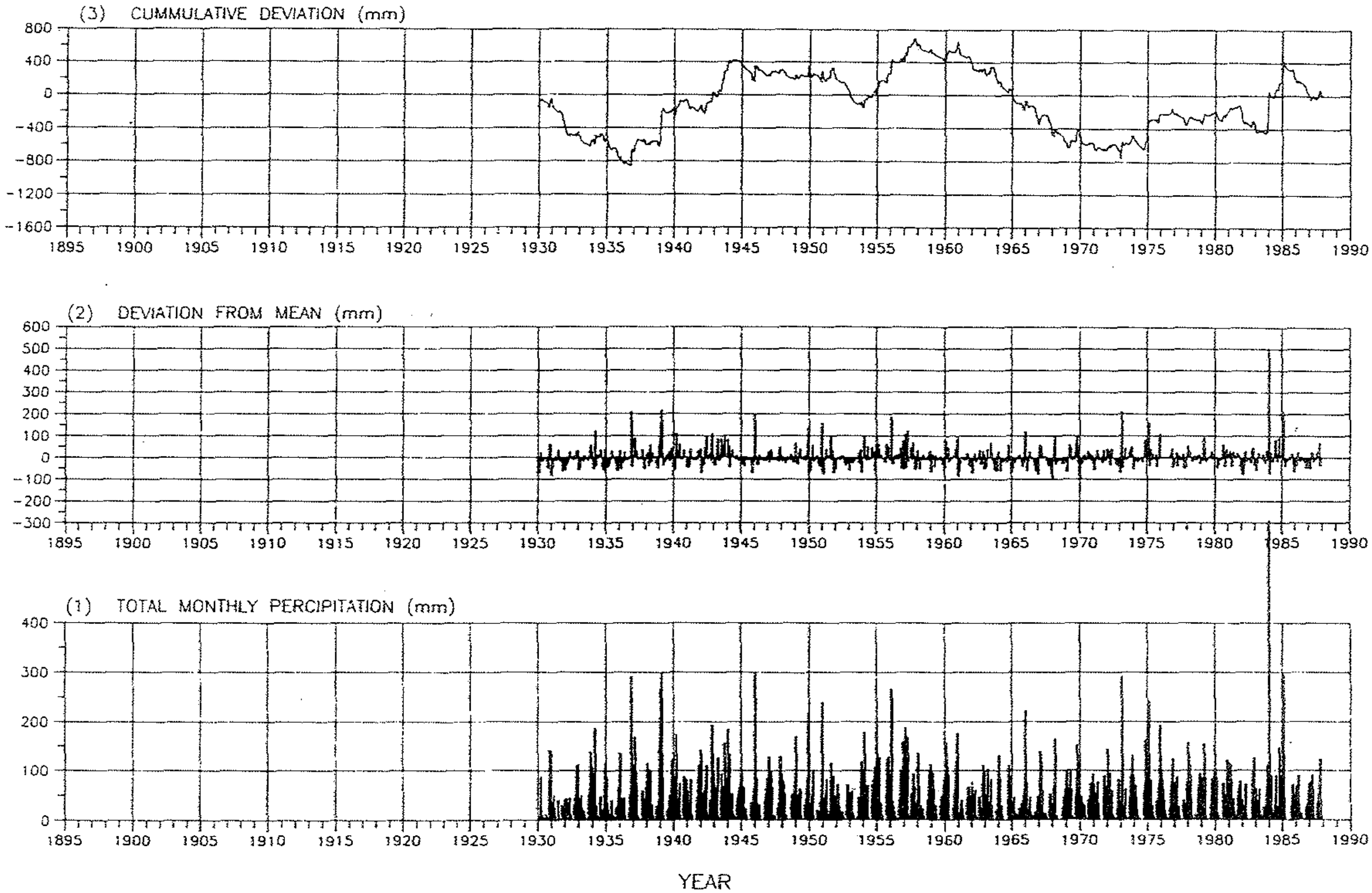
STATION NAME: BIG BEND (WISSELRODE)	MONTH	PRECIPITATION (mm) for 1922 to 1975 RAINFALL MAX	RAINFALL MEAN	RAINFALL MIN	RAIN-DAYS MAX	RAIN-DAYS MEAN	RAIN-DAYS MIN	MAX-24 HR RAIN[1]	TEMPERATURE (°C):1950 to 1986 ABS MAX	AVE MAX	MEAN	AVE MIN	ABS MIN	PAN EVAPORATION (mm):1980 to 1988 MAX	MEAN	MIN
ID No: ?	OCT	166	49	4	8	3.8	0	N.A.	42.2	32.0	24.6	17.2	5.0	254.2	206.1	161.2
Map No: 64	NOV	235	80	7	12	5.3	1	N.A.	40.7	31.6	25.0	18.4	7.4	237.0	202.5	144.0
	DEC	435	85	5	11	4.9	1	N.A.	42.3	32.6	26.7	20.7	8.6	263.5	231.0	198.4
LAT : 26° 49' S	JAN	305	93	5	10	5.2	1	N.A.	44.0	33.9	27.6	21.2	11.9	257.3	237.0	217.0
LONG : 31° 55' E	FEB	264	68	1	13	4.5	0	N.A.	40.5	31.6	25.9	20.2	11.2	246.4	201.9	151.2
ELEV : 155	MAR	334	59	5	18	4.2	1	N.A.	40.0	31.4	25.6	19.8	9.5	229.4	198.7	158.1
	APR	133	37	3	8	3.1	0	N.A.	39.5	29.9	22.9	15.9	5.5	183.0	146.0	126.0
RECORD (yrs):	MAY	87	22	0	6	1.5	0	N.A.	36.5	26.7	18.5	10.3	1.5	189.1	128.8	108.5
Precip: 51	JUN	86	14	0	4	1.2	0	N.A.	37.5	26.2	16.5	6.7	-6.7	114.0	97.7	78.0
Temp: 32	JUL	65	11	0	5	1.1	0	N.A.	38.3	25.9	16.3	6.7	-1.9	124.0	109.2	83.7
Evap: 8	AUG	52	9	0	4	0.7	0	N.A.	39.0	28.8	19.3	9.8	-6.5	167.4	146.0	111.6
	SEP	142	30	0	7	2.3	0	N.A.	42.4	30.2	22.5	14.7	0.3	204.0	168.7	111.0
MONTHLY TOTAL		435	46.4	0	18	3.2	0	N.A.	44.0	30.1	22.6	15.1	-6.7	263.5	172.8	78.0
(Year)		1938			1925									1987		1984
ANNUAL TOTAL[2]		980	557	310	25	37.8	52									
(Year)		1975		1945	1945		1975									

NOTES: 1. This information was unavailable.
2. Annual maximum, minimum and totals are based on a calendar year (January–December) time period, not a seasonal year (October–September) as for other climate statistics.

STATION NAME: BULEMBU	MONTH	PRECIPITATION (mm) for 1936 to 1978 RAINFALL MAX	RAINFALL MEAN	RAINFALL MIN	RAIN-DAYS MAX	RAIN-DAYS MEAN	RAIN-DAYS MIN	MAX-24 HR RAIN	TEMPERATURE (° C) for 1941 to 1986 ABS MAX	AVE MAX	MEAN	AVE MIN	ABS MIN
ID No: 519/237	OCT	399.0	153.4	42.2	20	14	7	118.1	35.1	23.0	17.4	11.8	2.7
Map No: 4	NOV	420.6	212.2	82.8	21	16	9	131.3	34.6	23.4	18.5	13.5	5.6
	DEC	512.0	254.7	116.2	25	16	9	116.7	35.6	24.4	19.6	14.7	7.2
LAT : 25° 57' S	JAN	669.5	294.7	69.0	24	17	8	247.1	35.5	24.5	20.0	15.5	7.9
LONG : 31° 08' E	FEB	618.2	263.7	80.1	22	15	7	290.6	33.2	24.2	19.9	15.5	1.1
ELEV : 1167 M	MAR	424.4	192.8	72.7	19	13	6	213.5	33.0	23.8	19.2	14.5	5.8
	APR	329.5	103.7	12.3	17	10	5	83.6	30.8	22.8	17.7	12.6	4.6
RECORD (yrs):	MAY	179.2	44.2	0.6	12	5	1	117.6	30.0	21.0	15.3	9.6	2.6
Precip: 42	JUN	136.4	25.4	0.0	9	3	0	135.9	26.2	18.9	12.9	6.8	-1.2
Temp: 44	JUL	164.3	27.5	0.0	12	3	0	65.0	27.0	19.5	13.2	6.9	-0.7
	AUG	212.1	37.2	0.6	13	6	1	79.2	31.4	21.0	14.7	8.3	0.1
	SEP	207.1	79.8	6.7	15	8	4	83.6	33.5	22.2	16.5	10.7	0.4
MONTH STATS		669.5	146.3	0.0	25	10.6	0	290.6	35.6	22.4	17.0	11.7	-1.2
(Year)		1955			1975			1939					
ANNUAL		2677.9	1689.3	1039.6	148	126	99						
(Year)		1954-55		1963-64	1971-72		1940-41						

CUMULATIVE DEVIATIONS FROM MEAN MONTHLY RAINFALL DATA FOR:

Fig. C-1



NOTES:

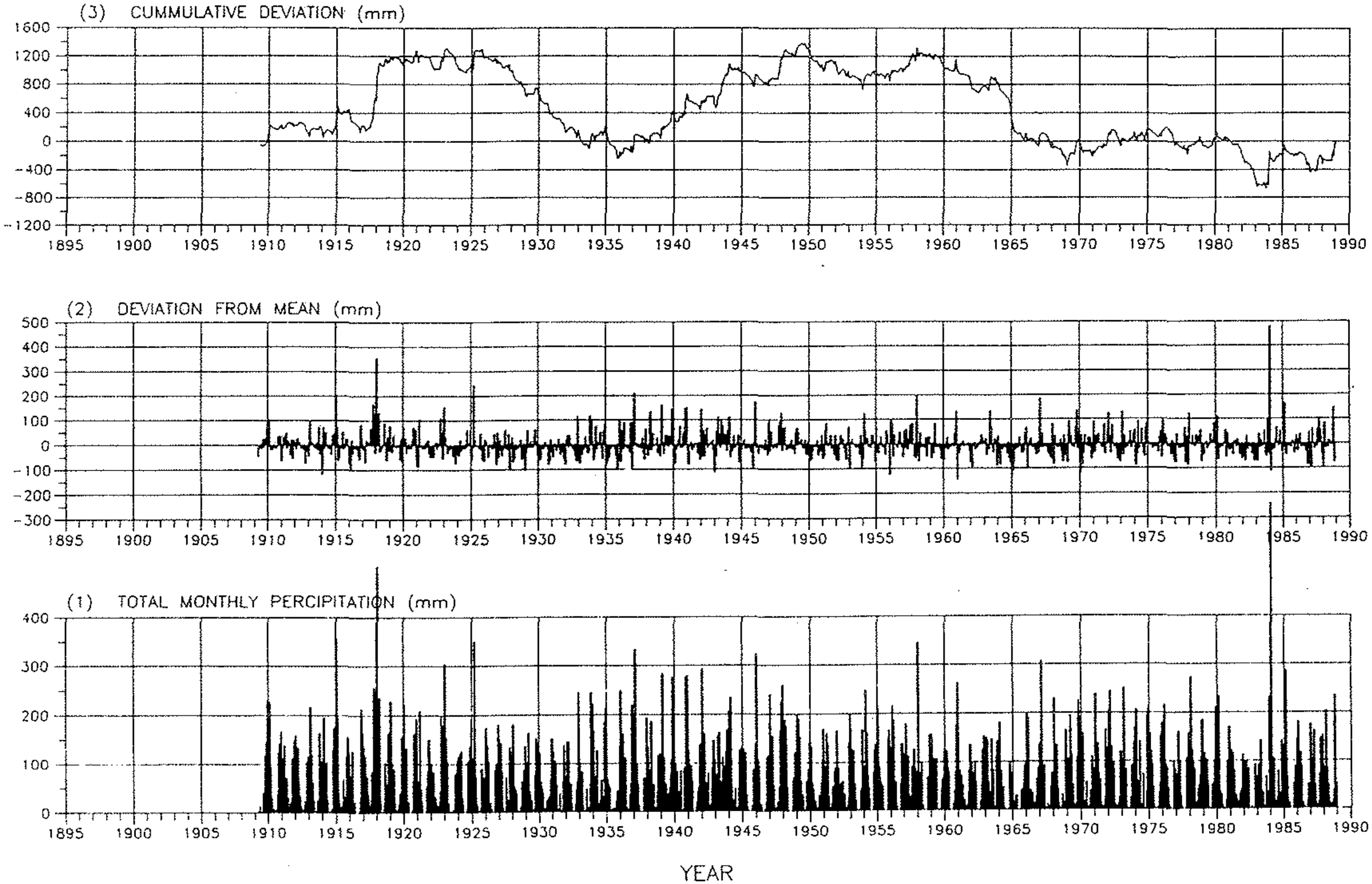
1) Deviations are calculated from each of the twelve month means.

2) See location of climate station 63 on Fig. 8

2) See location of climate station 63 on Fig. 8

CUMULATIVE DEVIATIONS FROM MEAN MONTHLY RAINFALL DATA FOR:

MANKAYANE CLIMATE STATION



NOTES:

1) Deviations are calculated from each of the twelve month means.
2) See location of climate station 49 on Fig. 8

Fig. C-2

GROUNDWATER RESOURCES OF SWAZILAND

APPENDIX D

SUPPLEMENTARY INFORMATION ON SWAZILAND GEOLOGY

APPENDIX D

TABLE OF CONTENTS

ADDITIONAL INFORMATION ON SWAZILAND GEOLOGY

The following discussion diverges somewhat from a conventional presentation of geological units in that, although they are described more or less in order of increasing age, there is some divergence from this due to the lumping together of various granitic rocks of different ages, both because of uncertainty as to their age inter-relationships, and because of their similar hydrogeologic characteristics.

D.1 GREENSTONE BELT (SWAZILAND SYSTEM)

D.1.1 PHYSIOGRAPHY OF GREENSTONE BELT

The Barberton Greenstone Belt is an area of rugged, mountainous terrain and deeply incised rivers. Swaziland's highest peaks (including Mount Emlembe, at 1862m-asl Swaziland's highest) are within this belt. Located in the northwestern part of Swaziland, the Greenstone Belt is the southernmost extension of the Barberton Mountainland of South Africa.

Average annual precipitation varies from about 1,000mm to over 1,700mm, and is strongly seasonal. The town of Bulembu, for example, has an average annual precipitation of 1,750mm, of which 80% falls in the period October to March (Barton, 1982). Swaziland's highest recorded annual rainfall was in this belt - 3,300mm in 1955 near Pigg's Peak.

Soil development is poor on the steeper slopes although, in many places, pronounced sub-tropical weathering and breakdown of the near-surface bedrock as a result of the high rainfall has resulted in deep, nutrient-poor soils.

Vegetation is usually sparse on the more exposed areas, where sour mountain grassland is the dominant vegetative cover. A thick growth of indigenous bush and trees is common in deep river valleys and gorges. There are extensive man-made pine and eucalyptus forests in the area around Pigg's Peak.

The Komati, Lomati, and Mbuluzi Rivers and their tributaries are the major streams draining the area. Many of the flows originate from springs, and flows of most streams are perennial. Many of the streams follow lines of structural weakness, and larger streams may follow major fault zones over much of their stretch. Many tributaries flow north-west wards or south-west wards, a direction corresponding with shears and tensional faulting (Jones, 1963). Basic dykes within the Greenstone Belt tend to weather more readily than the intruded bedrock, and their presence is often marked by cols or gullies in the topography.

D.1.2 GREENSTONE BELT - GEOLOGY

The Barberton Greenstone Belt is thought by many workers to be the oldest, best preserved, and least metamorphosed vulcano-sedimentary succession known (Kent, 1980). Hunter (1961) assigned System status to the entire stratigraphic succession, and Series status to its three sub-units. This report, however, uses the terminology of Barton (1982) and Wilson (1982) who termed the entire succession the Swaziland Supergroup, comprised of the Onverwacht, Fig Tree, and Moodies Groups. Wilson (1982) assigns an age of 3540 Ma to the Onverwacht Group, which is only slightly younger than the age assigned to the unit that is believed to include Swaziland's oldest rocks, the Ancient Gneiss Complex (Ngwane Gneiss).

Hall (1918) considered the "Jamestown Series" to be intrusive into the vulcano-sediments, while Hunter (1961, 1966) called this unit the "Jamestown Complex". Subsequent work has shown that this unit does not exist as a separate entity, but is merely Swaziland Supergroup rocks thermally metamorphosed and sheared along major faults (Kent, 1980).

The Onverwacht Group forms the basal sequence of the greenstone belt. It consists in large part of basic and ultrabasic lavas, regionally metamorphosed to talcose and talc-carbonate schists and amphibolites, and extensively silicified. Metasediments, including greywacke, chert, marl, ironstone, and shale, are relatively minor within the sequence.

The Onverwacht Group is conformably overlain by the sediments of the Fig Tree Group, consisting of coarse greywackes, shale, phyllite, quartzite, and conglomerate. A thick zone of banded iron formation, which includes the Ngwenya iron deposit, occurs within the Fig Tree Group.

Deposition of the conglomerates, quartzites, and shales of the Moodies Group followed deformation and partial erosion of the Onvérwacht and Fig Tree Groups.

Regional metamorphism to greenschist facies, and tight folding along steeply plunging northeast-southwest striking fold axes, together with high-angle thrust faulting toward the interior of the greenstone belt followed, and was superseded by northwest-trending cross-folding. The entire belt has been telescoped by thrust faulting, resulting in much repetition of lithologic sequences.

Barton (1982) estimates the total stratal thickness of the Swaziland Supergroup in Swaziland to be less than 5 km.

Contact metamorphism by the Lochiel (AG3) granite has resulted in abundant talcose rocks adjacent to the granite.

D.2 PLUTONIC ROCKS

The term "plutonic" may be used in its general sense to include all intrusive igneous rocks, and includes granites, granodiorites and gneisses, as well as smaller intrusive bodies such as granophyres, diabases and dolerites. Using this definition, most of Swaziland's Highveld and Middleveld areas are underlain by plutonic rocks, while smaller intrusives (dykes and sills) are common in the Lowveld.

D.2.1 GRANITES - GEOLOGY

The 1982 geological map of Swaziland shows four general ages of granites: the Lochiel Granite, dated at 3,028 m.y.; the Hlatikulu Granite, dated at 2,650 m.y., which contains Xenoliths of the updated Kwetta/Mtombe Granites which are therefore older than the Hlatikulu; and the Mswati Granites, dated at 2,550 m.y. On the older 1:50,000 scale geological maps, the Lochiel and Hlatikulu Granites were mapped as the AG3 unit, the Kwetta/Mtombe Granites as AG4, and the Mswati Granites as AG5.

The Lochiel Granite is coarse to fine-grained; the Hlatikulu, coarse to medium-grained; and both the Kwetta/Mtombe and Mswati Granites are coarse-grained. The Lochiel Granite (AG3) is the most widespread. The Mswati Granites (AG5) are the youngest, and were emplaced in several discrete plutons, which have been named the Mbabane, Nkalangeni, Malandela, Ngwempisi, Sicunusa, Sinceni, Mooihoek and Mhlosheni plutons (Wilson, 1982).

Pegmatites are abundant in the Lochiel Granite, where they have sharp contacts and appear to fill joints (Hunter, 1957). Swaziland's "Tin Belt" is developed in an area of cassiterite-bearing pegmatites, which are associated with a more sodic phase of the Lochiel Granite.

Pegmatites are absent from the Mswati Granites (AG5). These are steep-sided, sharply transgressive bodies exhibiting excellent jointing (Hunter, 1957).

Wilson (1980; sheet 24) has noted that all the granitic rocks are well jointed, and the courses of all the major rivers in granitic areas are controlled by joints.

D.2.2 GNEISSES (GN)

Wilson (1982) has named five different gneissic units within Swaziland. These are the Ngwane Gneiss, dated at 3,555 m.y. and equated to the Ancient Gneiss Complex of Hunter (1969); the Tsawela and Mhlatuzane Gneiss, dated at 3323 m.y.; a younger Nhlangano Gneiss; and the Mahamba Gneiss of uncertain age. The Ngwane Gneiss is the most widespread. This was referred to as the Swaziland System "infra-structure" by Hunter (1957). Exposures are confined largely to rapids on the major rivers (Hunter, 1957). Amphibolites, and more rarely serpentinites, are rather common within the Ngwane Gneiss as zones, narrow bands, or small ovoid bodies. Pegmatites are abundant, occurring as dykes, veins or pods. Dyke pegmatites have sharp contacts and appear to be related to joint and fracture directions (Hunter, 1957). Hunter (1966) included this unit in his Ancient Gneiss Complex (Mgn), and as Agd1 unit of granodiorite gneiss (Wilson (1979; sheets 16, 17, etc.) called this unit the Bimodal Suite of the early Archaean Ancient Gneiss Complex.

Tsawela Gneiss is a distinctive dark hornblende/biotite tonalite gneiss, which appears to intrude the Ngwane Gneiss. The Tsawela Gneiss was mapped by Hunter (1966) as a hornblende granodioritic gneiss phase of his Agd1 unit. Like the Ngwane Gneiss, it has abundant amphibolite inclusions, and is cut by dykes and veins of granite, pegmatite, quartz and diorite.

Mhlatuzane Gneiss (Wilson, 1980 and 1982, sheet 24;), is a hornblende-bearing tonolite gneiss of plutonic form, which is commonly foliated. It is present only on map sheets 24 and 25. Both dolerite dykes and amphibolite xenoliths are rather common.

Nhlangano Gneiss is a pale coloured, pinkish-red weathering quartzo-feldspathic gneiss of granitoid aspect, so much so that Hunter (1966) had included the main portion of this unit on sheets 28 and 29 in his AG3 unit. This unit has the form of folded, mantled gneiss domes. Amphibolite bodies and dolerite dykes are relatively scarce in this unit.

Mahamba Gneiss is present mainly on sheets 24 and 28. This gneiss was included by Hunter (1966) in his Ancient Gneiss Complex, while Wilson (1980; sheets 24 and 28) included it in this Bimodal Suite. The rocks comprise high-grade semi-pelitic garnetiferous gneisses which Wilson (1982) considers to be considerably younger than the Ngwane Gneiss. Dolerite dykes and amphibolite bodies are fairly common in this unit.

D.2.3 GRANODIORITES (GD)

Granodiorites are present in the relatively widespread Usutu Intrusive Suite, and occur in a more confined area near Mliba, where they are called the Mliba grandiorite (Wilson, 1982). The two units have different characteristics.

The Usutu Intrusive Suite has the form of a composite batholith and has been dated at 3,350 m.y. (Wilson, 1982). The rocks are coarse to medium grained and include quartz diorites, diorites, lenco-tonalites and quartz gabbros, as well as granodiorites. Amphibolite bodies and dolerite and diorite intrusions in the form of dykes and sills are relatively common.

This unit is characterized as having very deep zones of decomposition, especially in the area south west of Manzini where quartz diorites are common (e.g. the Malkerns and Luyengo areas) Hunter, 1961).

The Mliba granodiorite has been dated at 2,879 m.y., and was emplaced as a pluton (Wilson, 1982). It is coarse grained, foliated at the margins, is not cut by pegmatites, and dolerite intrusives and amphibolite bodies are rare.

D.3 PONGOLA SUPERGROUP

D.3.1 INSUZI GROUP

The Insuzi Group was deposited in the mid-Archean within a cratonic basin lying on the eroded top of the Lochiel Batholith (Wilson, 1982). It is a predominantly volcanic succession of rocks occurring in two separate areas of Swaziland. The main belt of strata centres on the Mahlangatsha area in sheet 23, while the other is located south and southwest of Maloma in sheet 30. The group is made up mainly of fine-grained, considerably altered andesitic and felsitic lavas, which are amygdaloidal in places. Lenticular, altered sedimentary beds of phyllite, schist and quartzite are interlayered within the succession.

Wilson (1982) gives an age of 2910 Ma to the Insuzi lavas.

D.3.2 MOZAAN GROUP

Mozaan Group sediments lie disconformably over the Insuzi Group, and cover a somewhat larger area than the Insuzi. The group consists of quartzites interbedded with shales, which are often altered to slate, phyllite, or schist. Hunter (1963) has divided the succession into a series of 14 quartzite and 14 shale horizons, capped by a 150 metre thick, fine-grained, amygdaloidal basalt.

The quartzites are light-coloured, variable in grain size, well-jointed, and form prominent outcrops. Bands and interbeds of conglomerate occur in the lower quartzite horizons.

Hunter (1963) gives a maximum total thickness of 4,260m to the sequence, of which the lower 1,120m, exposed in the Mahlangatsha-Gege area in map-sheets 23 and 28, is predominantly arenaceous, and the remaining upper portion, in the Kubuta area in map sheets 24, 25, and 29, is predominantly argillaceous.

D.4 USUSHWANA COMPLEX

The Usushwana Complex was named by Hunter (1950). It is a layered, mostly basic to ultrabasic intrusion comprising a suite of rocks ranging from pyroxenite to granophyre. An early pyroxenite phase is cut by later gabbros, microgranites, and granophyres. The main body of the intrusion has a dyke-like form some 8 km in maximum width, with steeply inward-dipping sides. It has a northwest-southeast trend across map-sheets 11 and 17, and is believed to have been intruded along lines of structural weakness in the Lochiel granite and the Swaziland Supergroup sediments (Hunter, 1957). Smaller satellite bodies and gabbroic dykes on either side of the main intrusion are considered to be part of the same complex. Fine-grained sill-like intrusions near the margins of some of these bodies dip at angles of about 45° towards the satellite bodies. Both the gabbro and pyroxenite are dark, medium to coarse grained rocks. The granophyres are variable in grain size, and exhibit well-developed jointing parallel to the alignment of the granophyre body (Winter, 1965).

Two thick, fairly extensive sill-like bodies, one located southeast of Mankayane on sheets 17 and 22, and the other along the border with South Africa on sheets 16 and 23, are assigned to the Usushwana Complex. Both are composed of medium grained gabbro and uniformly grained dark granophyre and microgranite. The sill-like body at the first-mentioned location is intruded along the base of the Insuzi Group, has an estimated thickness of about 1200m, of which the basal 240m is gabbro, and dips to the SSE at about 40° (Hunter, 1957). The structure and dip of the sill at the second-mentioned occurrence is uncertain.

D.5 PRE-KARROO DYKES AND SILLS

The Archean rocks in Swaziland have been extensively invaded by swarms of dykes of both pre-Karroo and post-Karroo age. The pre-Karroo dykes mostly have the composition of diabase. Swarms of northwest-trending dykes in a regular pattern are very common in the northwestern part of the country, especially in sheets 5, 10, 11, and 16. Northeast-trending dykes, which appear to post-date these (Hunter, 1957) are also present. North-northwest trending dykes cut Fig Tree Group sediments north of Pigg's Peak, and other dyke directions occur.

Dyke widths vary from a few centimetres to over 60 metres. All but the smallest dykes are coarser grained in their interior than along their margins. Those in granitic terrain are generally more resistant to erosion than the country rock, and stand out as prominent ribs. The reverse is usually true in the Greenstone Belt sediments.

Pre-Karroo sills and sheets are not common. Quartz veins are locally common, particularly along fault lines in granitic terrain, and in the Fig Tree Group sediments.

D.6 KARROO SUPERGROUP

D.6.1 KARROO SEDIMENTS (DWYKA, ECCA, AND NKONDOLO GROUPS)

The Karroo sediments form a continuous belt in Swaziland's Lowveld. They extend the full north-south length of the country, over a distance of some 160 km, and have an east-west width of between 9 and 25 km. There are smaller areas of the lower part of the sequence (Dwyka Group and Lower Ecca) in the southwestern part of the country within the Middleveld and Highveld.

The main belt of sediments forms flat-lying terrain with elevations ranging from about 120m above mean sea level near the Lusutfu River, rising locally to over 500m in the southern part of the belt, as at Nkondolo Hills which rise to a peak of 733m, and at Nkutshu Hill which has a maximum elevation of about 630m.

D.6.1.1 Physiography of Karroo Sediments

Both the main belt of Karroo sediments and the overlying Sabie River basalts, are in the driest part of Swaziland. Mean annual rainfall varies from less than 600mm up to almost 1000mm in higher areas.

Vegetation along the main belt is mostly Acacia savanna, with moister savanna in the western part (Goudie and Price Williams, 1983).

The main soil types are similar to those formed on the Sabie River basalts, i.e. stratified pseudopodsolic soils and red-brown soils of the subarid tropics, while drainage also is similar to that of the basalts (refer to section on basalts for a fuller description of soil types and drainage).

The Lebombo stage rhyolites form their own physiographic division, the Lebombo Mountains, extending the full 100 km length along the eastern border of Swaziland, from the Transvaal border in the north to the Lusutfu River boundary with Natal in the south. They continue southward into Natal, northward into Transvaal and Mozambique and hence into Zimbabwe, and have a total length of some 600 km.

The rhyolites form a prominent, elevated plateau with a steep westward-facing escarpment overlooking the Lowveld. The escarpment is up to 300m high in its southern part within Swaziland, and becomes less prominent to the north. The land surface of the plateau slopes gently eastward into Mozambique. Much of the higher western part of the plateau exceeds 500m in elevation while a maximum elevation of 777m is attained at a point just south of Siteki.

A thin sliver of the rhyolites is also present along the border with South Africa in the area south of the Lusutfu River, where the top of the escarpment forms the boundary between Swaziland and the Republic of South Africa.

Three of Swaziland's major eastward flowing rivers, the Lusutfu, Mbuluzi and Ngwavuma, cut through the Lebombo range, and Swaziland's lowest point at less than 40m-asl is reached along the Lusutfu River where it enters Mozambique. Approximately 1250 sq km (about 7% of Swazilands's total land area of 17,565 km) is underlain by the Lebombo rhyolites.

D.6.1.2 Karroo Sediments - Geology

The Karroo sediments form the lower part of the Karroo Supergroup (Wilson, 1982), and include from the base upwards, the Dwyka Group, Ecca Group, and Nkondolo Group of sedimentary rocks. The Nkondolo Group includes the Molteno Beds, Red Beds, and Cave sandstone as mapped on the 1:50,000 scale maps of Swaziland.

The Dwyka Group is made up of tillite, conglomerates, and pebbly sandstones and claystones of glacial origin. These sediments are only discontinuously present at the base of the Karroo sequence, reflecting preservation of glacial materials deposited within valleys or in topographically low areas. Wilson (1982) mentions outwash sediments laid down in a partially exhumed U-shaped glacial valley along the southwestern border of the country.

The overlying Ecca Group has a widespread Lower Ecca claystone member, which Wilson (1982) suggests is of possible prodeltaic origin, and is overlain by the thick prograding fluvio-deltaic sequence of the Middle and Upper Ecca members, which includes sandstones, coals and claystones, and which may exceed 700m in thickness. The sandstones of this sequence are commonly feldspathic and micaceous, with well developed cross-stratification.

The Nkondolo Group represents continental sedimentation. This unit contains well developed sandstones, pebbly sandstones, and claystones of both fluvial and aeolian origin.

D.6.2 SABIE RIVER BASALTS (BA)

D.6.2.1 Physiography of Basaltic Terrain

The name Drakensberg Stage basalts was used on the 1:50,000 geological map sheets of Swaziland (sheets 4, 8, 14, 20, 21, 26, 27 and 31). Wilson (198) used the name Sabie River Basalts, which will be used in this report. The basalts are confined almost entirely to the eastern part of Swaziland's Lowveld, with only a very small portion being present in the Lebombo Mountains at a point just west of Siteki. The basalts run the full north-south length of the country, a distance of some 150 km, in a belt varying from 6 to 22 km in width.

Elevations reach in excess of 400m (e.g. west of Siteki) and fall to below 80m above mean seal level along the Lusutfu River east of Big Bend. Relief is typically very low and subdued, except where the basalts have been hardened and baked by intrusive activity, and are as a result more resistant to erosion, as near the granophyre intrusion near Siteki, at Mananga Ridge, and in the area of dyke swarms, which is a northward extension of the Rooirand of Natal, extending from the Natal border almost to the Lusutfu River. The basalts are in the driest part of the country. Mean annual rainfall varies from less than 600mm per year (e.g. 551mm at Lavumisa), to over 800mm per year at Mananga Ridge.

The main soil types are red brown soils of the subarid tropics, (soils with little organic material which are found in the dry parts of the Lowveld), and pseudopodsolic soils, which are stratified soils with a sandy horizon at the surface and a clayey zone beneath (Goudie and Williams, 1983). Much of the land underlain by basaltic rocks is well suited for many types of agriculture, as witnessed by extensive irrigated fields of sugar cane and citrus orchards in the areas of Big Bend and Simunye.

Native vegetation consists of sweet grassland, with scattered deciduous and drought resistant trees, such as Acacias and other species of thorn trees (Goudie and Williams, 1983).

Three of Swaziland's major rivers, the Mbuluzi, the Lusutfu, and the Ngwavuma, flow eastwards across the basaltic belt into Mozambique and Natal. The tributary streams from the basaltic terrain which flow into these rivers, as well as those draining southwards to the Pongolo River system of Natal, have generally very low gradients because of the flat terrain. They normally carry little water and are usually dry during the drier months of late winter.

D.6.2.2 Basalts - Geology

The Sabie River basalts are tholeiitic (olivine-poor). They weather readily, and as a consequence are poorly exposed over much of their extent. Hunter (1961) and Urie and Hunter (1963) recognize four major types: the Lubuli type, which is most common; an interbedded porphyritic Mgwanwini type; the Nsoko type; and a more localized Sinyamantulu type occurring near the base of the succession. The distinction between the types is based on texture and lithology.

The Lubuli type is found throughout the entire length of the basaltic belt. It forms a monotonous succession of drab olive green to dark greyish green amygdaloidal basalt, which weathers readily. White amygdales up to a few inches in diameter are filled with quartz, carbonate or various zeolites. Small blackish amygdales consisting of epidote, chlorite minerals and magnetite, are fairly common.

The Mgwanwini type is interlayered with the Lubuli type, and is distinguished from the Lubuli by the presence of feldspar phenocrysts up to two or three centimetres in length. This unit forms a low ridge in the middle part of the basaltic sequence between the Ngwavuma and Lusutfu Rivers on sheet 26, and has been identified in the middle and upper portions of the sequence north of the Lusutfu River. Exposures, however, are poor. The Nsoko type normally is dark green in colour, but may weather to reddish brown. Patches of green glass rimmed by magnetite are common. Large amygdales filled by zeolites, and more rarely epidote, are found towards the top of the unit. The Nsoko type has not been identified north of the Lusutfu River, but to the south is located between the Rooirand hills to the west and the Lebombo rhyolites to the east. This unit weathers readily.

The Sinyamantulu type is located near the lower part of the basaltic succession, and is confined to a small area around Sinyamantulu hill in the southwestern part of sheet 26. It is compact and dark in colour and mauvish green in colour. Numerous white amygdales filled with carbonate, epidote, and chlorite minerals are present, as well as phenocrysts of feldspar, usually altered to carbonate or epidote.

Smaller occurrences of other types of basalt have also been observed, including non-amygdaloidal, dark coloured, almost black basalts of high specific gravity on Fahlaza Hill (in western part of sheet 31), and on Ndcandu Hill, in the southwestern part of sheet 26. The former occurrence contains abundant magnetite, and the latter is an olivine basalt, the only such occurrence noted in Swaziland. More resistant flows which form low ridges are in places interbedded with the basalts, most commonly in the upper part of the succession.

Urie and Hunter (1963) state that exposures are too poor to allow for reliable dip measurements to be made, nor to determine the amount and extent of strike faulting. The thickness of the basaltic succession therefore is difficult to assess. Hunter (1961), using the interbedded harder acid volcanics as a guide, assumed that the dip does not exceed 35°, and estimated a thickness of about 2000m. One of the present boreholes (BE4501) encountered reddish brown mudstones below basalt at a location well east of the belt of Karroo sediments. If this sediment can be assigned to the Nkondolo or Ecca Group of sediments, it would indicate hitherto unsuspected major faulting within the basalts and a lesser thickness of basalt than calculated by Hunter.

Swarms of dolerite dykes and extensive strike faults cut through part of the basaltic succession on map sheets 26 and 31 in the areas to the west of Big Bend and Lavumisa. The dolerite dykes are less susceptible to weathering than the basalts, and both these and the hardened, baked basalts near the dyke contacts form prominent closely spaced ridges. The resultant ridge and vale topography forms the northern extension of the Rooirand belt of South Africa. Urie and Hunter (1963) indicate a common dyke width of between 20 and 30m, and a westerly dip of 70 to 85°. The faults have a downthrow to the west. The associated dolerites are considered to be feeders of the basalt flows. The dyke swarms appear to be present over the entire basaltic succession on sheets 14 and 20, but are not as prominent or ridge-forming as on sheets 26 and 31. Outcrops are confined mainly to stream valleys. Very few dykes have been identified on map sheets 4 and 8, and it is assumed that dyke swarms are not present.

The composition of the dolerite dykes is almost identical to that of the basalts, although they are rarely porphyritic.

Pinkish white, medium grained granophyre plutons and associated fine grained dykes intrude the upper part of the basaltic succession on map sheets 4, 8, 14, and 20.

Wilson states that these were emplaced as steeply eastward-dipping sheets into the crest of the Lebombo Monocline, and may represent aborted feeders of the acidic lavas of the Lebombo Rhyolite succession.

D.6.3 LEBOMBO RHYOLITES (LR)

D.6.3.1 Physiography of Rhyolitic Terrain

Mean annual rainfall over the Lebombo Mountains averages about 840mm per year, which is approximately the same as n the Lower Middleveld.

The rhyolites are generally very resistant to weathering, soils are only weakly developed over much of the area, and there is a considerable area of bare rock and rock debris. There are, however, also some areas of relatively thick, fersialitic, reddish soil development, as near Siteki for example.

The upland parts of the plateau are not well wooded. They support vegetation similar to that in the Lowveld, sweet grassland with scattered acacias and other deciduous trees. The steep ravines and gorges along the streams and rivers however, are often heavily wooded and support a large number of tree species, many of which are coastal plain species which reach their western limit in these ravines.

The drainage divide of the Lebombo Mountains is located very close to the top of the westward facing scarp. The general impression over most of this belt is one of aridity. Runoff is rapid and stream courses are dry over much of the year. Most streams are rather deeply incised and flow eastward following the dip slope of the rocks, into Mozambique. They are joined by subsequent streams, northward and southward flowing tributaries following the approximate strike of the rocks.

D.6.3.2 Lebombo Rhyolites - Geology

The Lebombo Rhyolites are a thick succession of mostly acidic volcanic rocks disconformably overlying the Sabie River Basalts, although there are rhyolites interbeds, and some interfingering of rhyolites and basalts, in the upper part of the Sabie River. The rock composition of the "rhyolites" varies from rhyolite to dacite, both types containing phenocrysts of plagioclase, quartz, clinopyroxene, and magnetite in a fine-grained devitrified matrix.

Bristow and Cleverly (1976) have suggested that the rocks may have been deposited as devitrified or degassed ash flows, rather than as normal ash flows or as viscous lava flows, and class them as rheoignmbrites.

The rhyolites have been estimated to be a minimum of 5 km thick, of which about 4 km thickness is present in Swaziland (Cleverly, 1977). In making this calculation, Cleverly assumed an average easterly dip of 30°, with dips in the western part as high as 60° being recorded. Other authors have assumed dips of between 10 and 30°. The cross-sections on the Geological map of Swaziland (Wilson, 1982) indicate an average dip of less than 5°. It is obvious from the above-noted differences that determination of dips in the rhyolites can be difficult.

Hunter (1961) has noted "highly involved and over-folded pseudo-flow structures" in the rhyolites and states that dips are reliable only if taken at recognized contacts between flow units.

Cleverly (1977) has divided the formation into a series of "cooling units", each of which is a rapid succession of flows that have cooled together to form individual units ranging in thickness from a few tens of metres to 350m. Some 30 individual cooling units have been mapped in Swaziland.

Each cooling unit (or flow unit) has a vertical zonation as outlined below, although not all zones are necessarily present:

1) Capping of autobreccia and agglomerates,
2) Zone of contorted banding, grading downwards to:
3) Banded horizon,
4) An apparently massive welded zone, which forms most of the flow,
5) Streaky, banded zone often containing flattened pumice clasts,
6) A thin basal tuff zone.

Sandstone, chert and tuffaceous sandstone may be associated with the basal tuff zone. The ryholites are extensively veined in places by necontemporaneous hydrothermal fluids and gases, resulting in the formation of a pseudobreccia.

Hunter (1961) and Urie and Hunter (1963) state that the agglomerates are generally 15 to 30m, with occasional thicknesses of up to 90m. They are described as consisting of maroon or reddish brown angular fragments, generally of pebble size but ranging up to a few feet across, set in a yellowish brown to reddish brown, fine grained groundmass containing fragmented quartz and stained by iron oxide. There is usually a coarsening upwards in grain size, while the rock becomes less compact and more vesicular and pumaceous.

In northern Natal, Van Wyk (1963) has mapped several north-trending bodies (i.e. along strike) of ryholitic breccia which he called breccia dykes. These are believed to be the zones mapped in Swaziland by Cleverly (1977), and Wilson (1982) as autobreccias and agglomerates forming the upper zones of cooling units, as discussed above.

Only a few faults of any extent have been mapped, although there are many small faults at the western edge of the rhyolites, Granophyre and dolerite intrusions in the form of narrow dykes are rare but occasionally present. Cleverly (1977) states that all the dykes cutting the rhyolites seem to have a vertical dip.

D.6.4 KARROO INTRUSIVES

Dykes, sheets and sills of Karroo age dolerite intrude the Karroo Supergroup, as well as the older pre-Karroo rocks. They are particularly abundant in all forms in the Karroo sediments, while sheets and sills are common in the Archean rocks of southern Swaziland. They are believed to have been emplaced immediately prior to or concurrently with the Sabie River basalts (Wilson, 1982). They are usually medium to coarse grained and include porphyritic varieties. Quartz dolerites, which weather more readily than the normal variety are common in the Sitobela-Kubuta area in sheet 25. Karroo age dykes are present in the Greenstone Belt strata, striking slightly east of north at large angles to the more widespread northwesterly striking older diabase dykes (Hunter, 1957).

A dense swarm of north-south trending basic dykes in the Sabie River basalts were probably intruded at the end of the lava extrusion phase, but before the development of the Lebombo Monocline which tilted these intrusions to the west (Wilson, 1982).

A number of granophyre plutons elongated in a north-south direction have intruded the Karroo volcanic sequence close to the contact of the basic and acidic lavas. Dykes associated with the plutons have strike directions varying from northwest to east-northeast, and intrude both the acidic and basic volcanics. Dolerite dykes are rare in the Lebombo Rhyolite sequence. The granophyres are much more resistant to erosion than the surrounding basalt. They are usually medium grained and holocrystalline, while the associated dykes are fine grained and often porphyritic. The granophyres were emplaced as steeply eastward-dipping sheets into the crest of the monocline, and may represent aborted feeders (Wilson, 1982).

D.7 OTHER UNITS

These include Dwalile, Metamorphic Suite, Shiselweni Amphibolites and Mkhondo Valley Metamorphic Suite.

Wilson (1982) equates the rocks of the Dwalile Metamorphic Suite with those of the Onverwacht Group. The suite comprises a whole range of metamorphic rock types. Amphibolites are most common, but serpentinite, schist, quartzite, calc-silicate rocks, ironstone, and granulite are also represented. They crop out in refolded synclinal fold keels and other minor patches, mainly within the Ngwane Gneiss outcrop, but do not occur as xenoliths (Wilson, 1982). They are also present within other gneiss bodies, granodiorites and granites. Dwalile rocks are shown by Wilson to be present over the central and northern parts of Swaziland's igneous rock area, with the largest patches occurring on Map Sheets 16, 22, 23.

Wilson (1982) shows the Shiselweni Amphibolites to be present on Map Sheets 24, 25 and 28 in areas where the Dwalile Suite is not represented. He equates them with the

Insuzi Group, as they commonly underlie Mozaan rocks, and they are believed to have been metamorphosed from lavas. The amphibolites are often of considerable thickness and often occur as long linear bodies, for example, on Sheet 28, where the amphibolites lie between the Mahamba gneiss and Ecca Group sediments.

The Mkhondo Valley Metamorphic Suite comprises high grade metamorphic rocks, which are the equivalent of the Mozaan Group (Wilson, 1982). They consist mainly of quartzite, schist, and taconite, which are often caught up in rather tight, narrow synclinal folds over the Nhlangano and Mahamba gneiss. Other patches of these rocks are found within the Hlatikulu granites.

D.8 ALLUVIAL DEPOSITS

Swaziland's rivers have broad alluvial flats of Recent origin, containing sand and gravel, usually less than 35m thick, but often extending to well below river level. Middle and upper reaches of streams on the other hand, are often cut down into solid bedrock.

Older, higher alluvial terrace levels occur in many places, often perched on hillslopes as much as 20m above the level of existing valley bottoms. The alluvial material in these terraces is often cemented to form ferricrete.

D.9 ZONES OF WEATHERING

Tropical weathering results in disaggregation through chemical breakdown, and alteration of the constituent rock minerals. Weathering profiles can be many tens of metres thick. They have been well described by McFarlane (1987) and by Mkandawire (1987).

The following description is taken largely from their work.

A weathering profile contains several distinct zones which grade one into the other (Fig. 34). Above the fresh bedrock is a zone of saprock (McFarlane, 1987), broken and hydrated rock with chemically weathered surfaces on blocks of bedrock which remain fresh and unaltered in their centres. This zone grades upward into saprolite, sandy or gravelly, crumbling, decomposed bedrock which still retains the original rock structure. Colluvium forms the uppermost zone, a residuum which results when the saprolite becomes so weakened by leaching that it collapses. Relict rock textures and structures are no longer recognizable. Sandy clays, often with small quartz fragments, may be present at the base, grading upwards to clay, and capped by a soil profile. Boundaries of the different zones are gradational and not well defined. Recognition of all zones during drilling is not always possible, and precise location of boundaries is usually not possible. Hydrologically, the saprock and saprolite together, or some interval within them, forms an aquifer, and the overlying colluvium acts as a confining layer. In general, basic rocks are more susceptible than acidic ones to deep weathering, because the ferromagnesian minerals making up a large percentage of these rocks break down more readily.

Areas of relatively deep weathering in Swaziland include basaltic rocks near Lavumisa, and granodiorites and gneisses in the Malkerns and Ezulwini valleys.

D.10 STRUCTURAL FEATURES

D.10.1 REGIONAL FAULT ZONES

All rocks in Swaziland's stratigraphic succession have been affected by faulting to varying degrees. The faults trend predominantly in northerly, north-northeasterly or north-northwesterly directions, but all directions are possible.

Recognition of faulting within the softer or more deeply weathered rocks, such as the Karroo sediments and the Sabie River basalts, can be difficult. Sustainability of open fractures along fault planes is believed to be more likely in more rigid rocks, than in relatively soft sediments, where they would tend to be squeezed shut.

Faulting follows lines of structural weakness, and provides avenues for the later emplacement of dykes, quartz veins, or other intrusions, which often destroy the initial permeability that may have been present.

The nature of the faulting varies. High angle thrust faults are common in the Greenstone Belt, while block faulting may predominate in other areas. There is no evidence of faulting on the Pine Valley lineament, which transects Map Sheets 2, 5, 6, and 11 in a NE-SW direction, but northwest trending basic dykes either thin or terminate at this structure (Wilson, 1979), and the lineament is here assumed to be fault-controlled.

D.10.2 MYLONITE ZONES

Two major north-south trending mylonite shear zones affecting Archean granites and gneisses and Mozaan Group sediments, are present in central Swaziland, mainly on Map Sheets: 13, 19 and 24. These zones grade into narrow, often bifurcating, shears or faults at their extremities. Way (1961) indicates that the dip of the eastern zone, on sheets 13 and 19, is steeply eastwards at 65 to 75°. The western zone, on sheets 19 and 24 and trending into sheets 13 and 29, also has an eastward dip, but at shallower angles of 35 to 55°. The age of shearing is post-Mswati granite, and pre-Karroo (Hunter, 1961). Hunter cites much evidence of fault action. The rocks are dense, fine-grained, and often streaky, strained, and multi-coloured.

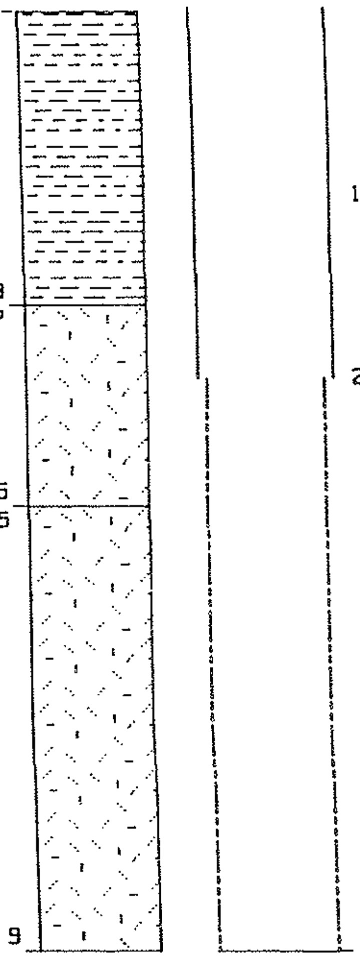
APPENDIX E

LOGS OF SELECTED HIGH YIELDING BOREHOLES

* AC08-01	* AM31-03	* BC27-01	* _K28-02
* AE15-02	* AM32-06	* BE09-01	* _O31-01
* AE24-01	* AP39-02	* BL46-01	* _W44-01
* AF41-03	* AR00-01	* BN16-01	* _XO8-01
* AG45-01	* AX14-01	* BO26-01	* _Z30-01
* AI29-01	* BA28-01	* BR45-01	

DRILLHOLE: AC0801

LITHOLOGY [1,2]	COMPLETED CONSTRUCTION [2,3]	DETAILED DESCRIPTION	DURING DRILLING DEPTH	WATER LEVEL	WATER FLOW	COMMENT
0 / 1235 — CLAY — 18.3 / 1216.7	154mm	REDDISH BROWN CLAY.				TOTAL DEPTH= 57.9 M. SWL= 11.18M. FIRST WATER: 4.0L/s FROM 29.0 M. FINAL YIELD= 4.0L/s FROM 29.0 M.
18.3 / 1216.7 — GABB — 30.5 / 1204.5	22.78m	WEATHERED GABBRO.	29.00	4.0L/s	WATER	CAS. LENGTH= 22.78 M. STICK UP= 0.25 M.
30.5 / 1204.5 — GABB — 57.9 / 1177.1	150mm; 57.9	FRESH, DARK GREEN, COARSE GRAINED GABBRO WITH LARGE EUHEDRAL CRYSTALS OF WHITE FELDSAR.	51.00		4.0	GEOPHYSICS: NONE. PUMP TEST: RATE:2.0L/s. DURATION: 960 MINS. MAX. D.DOWN: 8.22 M. WATER CHEM: TEMP.=24Deg. PH.= 8.2 EC.=84.1mSm.
		END OF HOLE.				



PLOT TITLE : HYDROGEOLOGIC LOG
FROM DEPTH : 0 m
TO DEPTH : 57.9 m

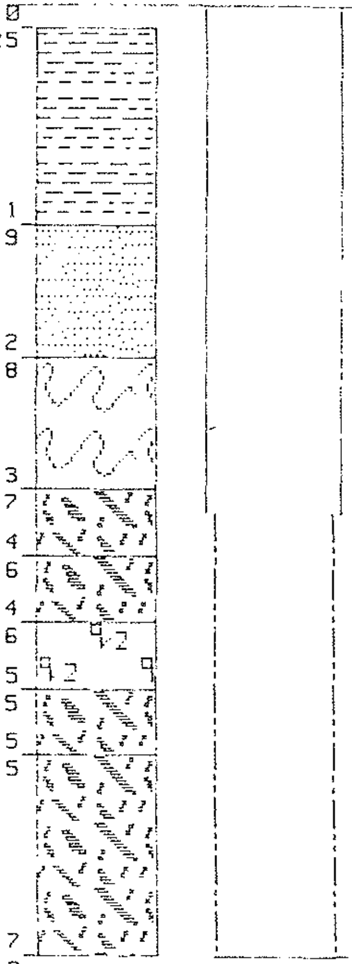
1,2,3.... NUMBERS REFER TO LITHOLOGIC NOTES

PROJECT : SWAZILAND GROUNDWATER SURVEY
STUDY : LITHOLOGY IN DRILLHOLE AC0801
DATE : Comp. 2nd DEC.1989

GEOMIN GROUNDWATER INFORMATION AND EVALUATION SYSTEM

DRAWN BY	CHECKED BY	HORZ SCALE	VERT SCALE	FIGURE	PAGE
C.M.		1:NTS	1:543	1	1

DRILLHOLE: AE1502



LITHOLOGY [1,2]	Depth / Elevation	COMPLETED CONSTRUCTION [2,3]	DETAILED DESCRIPTION	DURING DRILLING: DEPTH	WATER LEVEL	WATER FLOW
CLAY	0 / 725 – 9.1 / 715.9		REDDISH BROWN CLAYEY SOIL.			
SILT	9.1 / 715.9 – 15.2 / 709.8	154mm	LIGHT GREY TO WHITE SILTY SOIL.			
FRAC	15.2 / 709.8 – 21.3 / 703.7		WHITE, QUARTZ FRAGMENTS.			
GNSS	21.3 / 703.7 – 24.4 / 700.6	22.38m	GREY DEEPLY WEATHERED GNEISS.	22.38	1.0L/s	WATER
GNSS	24.4 / 700.6 – 27.4 / 697.6		LIGHT, SLIGHTLY WEATHERED GNEISS	24.40		1.00
QZMN	27.4 / 697.6 – 30.5 / 694.5		QUARTZ VEINS WITH IRON STAINS.			
GNSS	30.5 / 694.5 – 33.5 / 691.5	150mm	DARK FRESH AMPHIBOLITIC GNEISS.	30.50		1.00
GNSS	33.5 / 691.5 – 42.7 / 682.3	42.7	DARK GREY TO WHITE, FRESH GNEISS WITH INCEPIENT IRON STAINING ALONG JOINTING.	36.60		4.00
	42.7 / 682.3		END HOLE.	42.70		4.00

COMMENT:

TOTAL DEPTH= 42.7 M.

SWL= 6.56 M.

FIRST WATER: 1.0L/s FROM 22.38 M.
FINAL YIELD= 4.0L/s FROM 36.6 M.

CAS. LENGTH= 22.38 M.
STICK UP= 0.86 M.

GEOPHYSICS: NONE.

PUMP TEST:
RATE: 2.5L/s.
DURATION: 960 MINS.
MAX. D.DOWN: 15.05 M.

WATER CHEM:
TEMP.=21Deg.
pH.= 6.6
Ec.= 76 mSm.

PLOT TITLE : HYDROGEOLOGIC LOG
FROM DEPTH : 0 m
TO DEPTH : 42.7 m

1,2,3,... NUMBERS REFER TO LITHOLOGIC NOTES

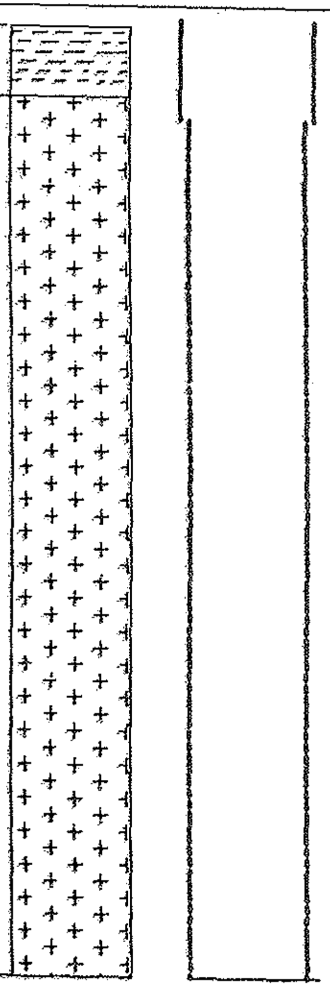
PROJECT : SWAZILAND GROUNDWATER SURVEY
STUDY : LITHOLOGY IN DRILLED HOLE AE1502
DATE : Comp. 16th JAN. 1991

GEOMIN GROUNDWATER INFORMATION AND EVALUATION SYSTEM

DRAWN BY	CHECKED BY	HORZ SCALE	VERT SCALE	FIGURE	PAGE
C.M.		1:NTS	1:399	1	1

DRILLHOLE: AE2401

LITHOLOGY [1,2]	COMPLETED CONSTRUCTION [2,3]	DETAILED DESCRIPTION	DURING DRILLING DEPTH	WATER LEVEL	WATER FLOW	COMMENT
0 / 681.3 CLAY 6 / 675.3	154mm 7.76m	REDDISH BROWN CLAY.				TOTAL DEPTH= 79.3 M. . SWL= 9.11 M. . FIRST WATER: 2.9L/s FROM 24.4 M. FINAL YIELD= 20.0L/s FROM 73.2 M. . CAS. LENGTH= 7.76 M. STICK UP= 0.65 M. . GEOPHYSICS: NONE. . PUMP TEST: NONE. . WATER CHEM: TEMP.= N/A. PH.= 7.6 EC.= 170mSm.
GRDT	150mm	COARSE GRAINED DEEPLY WEATHERED PEGMATITIC GRANODIORITE, CONSISTING OF PALE YELLOW BROWN BIOTITE.	24.40	2.9L/s	WATER	
			36.60		4.00	
			54.90		10.00	
			73.20		20.00	
79.3 / 602	79.3	END HOLE	79.3		20.00	



PLOT TITLE : HYDROGEOLOGIC LOG
FROM DEPTH : 0 m
TO DEPTH : 79.3 m

PROJECT : SWAZILAND GROUNDWATER SURVEY
STUDY : LITHOLOGY IN DRILLHOLE AE2401
DATE : Comp.13th OCT.1989

GEOMIN GROUNDWATER INFORMATION AND EVALUATION SYSTEM

DRAWN BY	CHECKED BY	HORZ SCALE	VERT SCALE	FIGURE	PAGE
C.M.	[signature]	1:NTS	1:734	1	1

1,2,3... NUMBERS REFER TO LITHOLOGIC NOTES

1,2,3,... NUMBERS REFER TO LITHOLOGIC NOTES

DRILLHOLE: AG4501

LITHOLOGY [1,2]	COMPLETED CONSTRUCTION [2,3]	DETAILED DESCRIPTION	DURING DRILLING DEPTH	WATER LEVEL	WATER FLOW	COMMENT
0 610 RYLT	154mm 150mm	PALE REDDISH BROWN WEATHERED PORPHYRITIC RHYOLITE WT WHITE PHENOCRYSTS OF FELDSPAR (0.1 TO 0.5MM SIZE) AND QUARTZ. IT HAS FINE GRAIN GROUNDMASS WHICH IS SLIGHTLY GLASSY. THERE ARE ABOUT 5% MAFIC MINERALS.	18.3 24.4 42.7 48.8 67.1 73.2	.15L/s	WATER 0.28 0.31 0.60 0.60 0.60	TOTAL DEPTH- 94.5 M. . SWL- 19.85M. . FIRST WATER: 0.15L/s FROM 18.3 M. FINAL YIELD- 0.60L/s FROM 48.8 M. . CAS. LENGTH- 2.0 M. STICK UP- 0.37 M. . GEOPHYSICS: NONE. . PUMP TEST: RATES:2;1.10 AND 1.11L/s. DURATION: 190 MINS. MAX. D.DOWN: 32.22 M. . WATER CHEM: TEMP.=23Deg. PH.= 6.9 EC.= 300mSm.
82.3 527.7 RYLT		FRESH PALE GREY PORPHYRITIC RHYOLITE.				
94.5 515.5	94.5	END HOLE.	94.5		0.60	

PLOT TITLE : HYDROGEOLOGIC LOG
FROM DEPTH : 0 m
TO DEPTH : 94.5 m

1,2,3,... NUMBERS REFER TO LITHOLOGIC NOTES

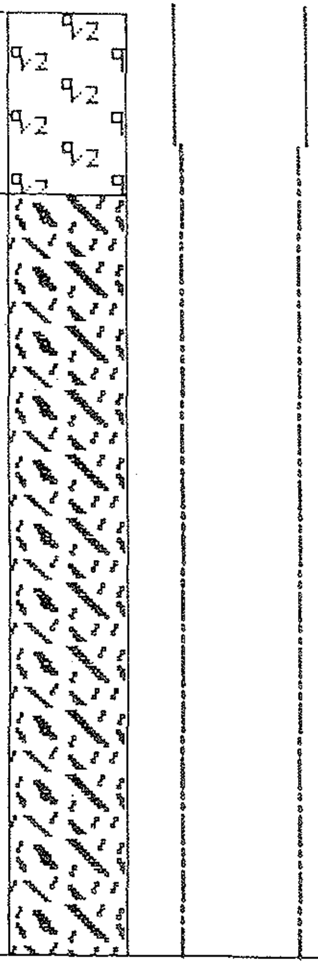
PROJECT : SWAZILAND GROUNDWATER SURVEY
STUDY : LITHOLOGY IN DRILLHOLE AH4501
DATE : Comp.31st MAR.1988

GEOMIN GROUNDWATER INFORMATION AND EVALUATION SYSTEM

DRAWN BY	CHECKED BY	HORZ SCALE	VERT SCALE	FIGURE	PAGE
C.M.		1:NTS	1:875	1	1 OF 2

DRILLHOLE: AI2901

LITHOLOGY [1,2]	COMPLETED CONSTRUCTION [2,3]	DETAILED DESCRIPTION	DURING DRILLING: DEPTH	WATER LEVEL	WATER FLOW	COMMENT
0 458 QZMN 7.6	154mm 5.39m	WEATHERED QUARTZ WT PIGMATITE.				TOTAL DEPTH= 76.2 M. . SWL= 34.54M. . FIRST WATER: 5.0L/s FROM 54.9 M. FINAL YIELD= 6.7L/s FROM 76.2 M. . CAS. LENGTH= 5.39 M. STICK UP= 0.5 M. . GEOPHYSICS: NONE. . PUMP TEST: NONE. . WATER CHEM: TEMP.=20Deg. PH.= 7.1 EC.= 540mSm.
450.4 GNSS	150mm	WEATHERED GNEISS CRS GRAINED WT SOME FELDSPAR & MAFIC MINERALS DARK GREY FROM 9.2-36.6M AND LIGHT GREY FROM 39.7-60.0M.				



PLOT TITLE : HYDROGEOLOGIC LOG
FROM DEPTH : 0 m
TO DEPTH : 39 m

PROJECT : SWAZILAND GROUNDWATER SURVEY
STUDY : LITHOLOGY IN DRILLHOLE AI2901
DATE : Comp. 3rd MAY,1988

GEOMIN GROUNDWATER INFORMATION AND EVALUATION SYSTEM

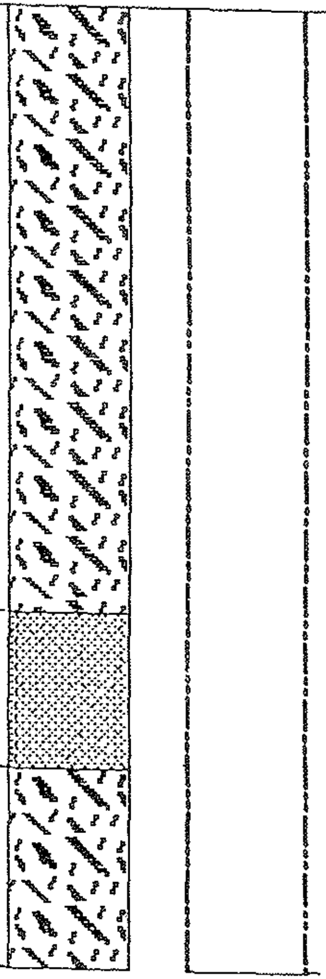
DRAWN BY	CHECKED BY	HORZ SCALE	VERT SCALE	FIGURE	PAGE
C.M.		1:NTS	1:353	1	1 of 2

1,2,3.... NUMBERS REFER TO LITHOLOGIC NOTES

DRILLHOLE: AI2901
DURING DRILLING

DRILLHOLE: AI2901

LITHOLOGY 1,2	COMPLETED 2,3 CONSTRUCTION	DETAILED DESCRIPTION	DURING DRILLING DEPTH	DURING DRILLING WATER LEVEL	DURING DRILLING WATER FLOW	COMMENT
			54.9	5.0L/s	WATER	
62.6 / 395.5 DOLR		GREENISH GREY DIABASE CONSISTING OF RAGGED LATHS OF GREEN HORNBLENDE, SOME FELDSPAR AND YELLOWISH OLIVINE.				
68.7 / 389.4 GNSS		LARGE GRAINED GNEISS WITH SOME HORNBLENDE CRYSTALS.				
76.3 / 381.7	76.3	END HOLE.	76.2		6.7	



PLOT TITLE : HYDROGEOLOGIC LOG
FROM DEPTH : 39 m
TO DEPTH : 76.3 m

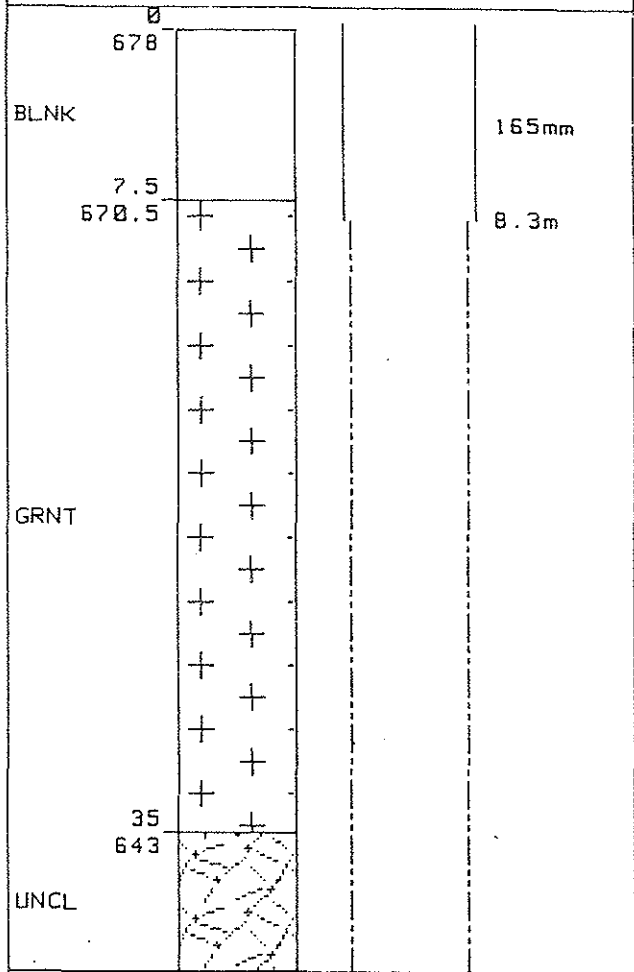
1,2,3,... NUMBERS REFER TO LITHOLOGIC NOTES

PROJECT : SWAZILAND GROUNDWATER SURVEY
STUDY : LITHOLOGY IN DRILLHOLE AI2901
DATE : Comp. 3rd MAY,1988

GEOMIN GROUNDWATER INFORMATION AND EVALUATION SYSTEM

DRAWN BY	CHECKED BY	HORZ SCALE	VERT SCALE	FIGURE	PAGE
C.M.		1:NTS	1:340	1	2 of 2

DRILLHOLE: AM3103

LITHOLOGY [1,2] / COMPLETED CONSTRUCTION [2,3]	DETAILED DESCRIPTION	DURING DRILLING: DEPTH	WATER LEVEL	WATER FLOW	COMMENT
	NO SAMPLES TAKEN. PINK WEATHERED GRANITE, MEDIUM GRAINED. ZONE OF VERY WEATHERED MATERIAL WITH SOME CLAY (GOUGE) 35-41.1M				TOTAL DEPTH= 85.0 M. SWL= 29.21M. FIRST WATER: 0.1L/s FROM 42.0 M. FINAL YIELD= 2.86L/s FROM 85.0 M. CAS. LENGTH= 8.3 M. STICK UP= 0.35 M. GEOPHYSICS: NONE. PUMP TEST: RATE:1.1L/s. DURATION: 1440 MIN. MAX. D.DOWN: 11.23 M. WATER CHEM: NONE.

PLOT TITLE : HYDROGEOLOGIC LOG
FROM DEPTH : 0 m
TO DEPTH : 41 m

1,2,3,... NUMBERS REFER TO LITHOLOGIC NOTES

PROJECT : SWAZILAND GROUNDWATER SURVEY
STUDY : LITHOLOGY IN DRILLHOLE AM3103
DATE : Comp.30th APR.1986

GEOMIN GROUNDWATER INFORMATION AND EVALUATION SYSTEM

DRAWN BY	CHECKED BY	HORZ SCALE	VERT SCALE	FIGURE	PAGE
C.M.		1:NTS	1:371	1	1 of 2

DRILLHOLE: AM3103
DURING DRILLING

DRILLHOLE: AM3103

LITHOLOGY [1,2]	COMPLETED CONSTRUCTION [2,3]	DETAILED DESCRIPTION	DURING DRILLING DEPTH	WATER LEVEL	WATER FLOW	COMMENT
636.9 GRNT 47.2	154mm	FINE GRAINED MAFIC ROCK WITH 30% PINK QUARTZ, MAFICS ALTERED TO CHLORITE.	42.0	.10L/s	WATER	
630.8 GRNT 59.5		MEDIUM GRAINED PINK GRANITE WITH TRACE OF EPIDOTE.	48.8		0.28	
			54.9		0.42	
618.5 GRNT 65.5		FINE GRAINED MAFIC ROCK WITH 30% QUARTZ, MAFICS ALTERING TO CHLORITE.	61.0		2.50	
612.5 GRNT 85 593	85	ALTERNATING MEDIUM GRAINED GRANITE AND VERY FINE GRAINED MAFIC ROCK ALTERING TO CHLORITE	67.0		2.50	
			73.0		2.50	
			79.0		2.50	
		END OF HOLE.	85.0		2.86	

PLOT TITLE : HYDROGEOLOGIC LOG
FROM DEPTH : 41 m
TO DEPTH : 85 m

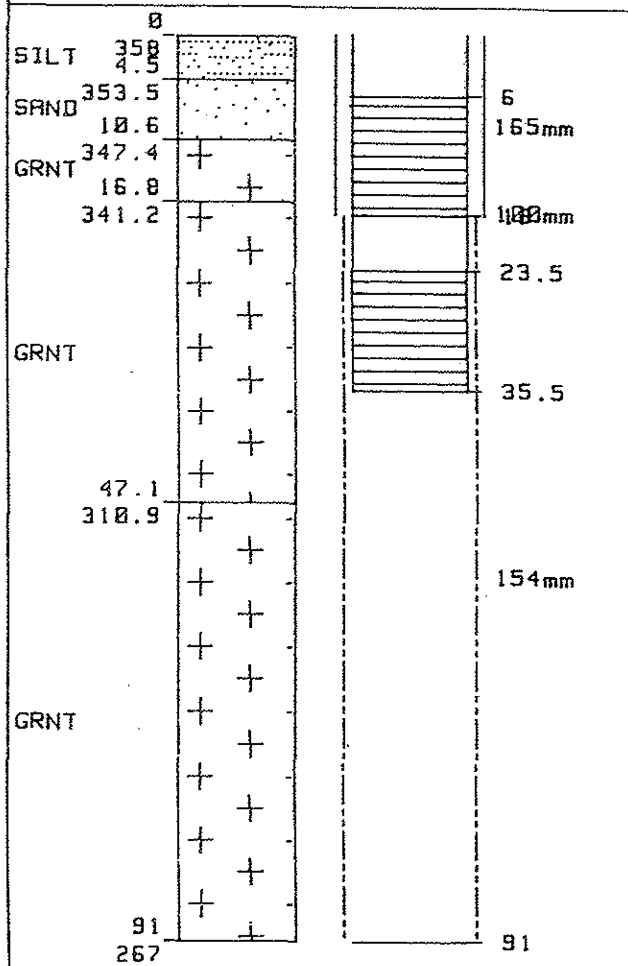
1,2,3,... NUMBERS REFER TO LITHOLOGIC NOTES

PROJECT : SWAZILAND GROUNDWATER SURVEY
STUDY : LITHOLOGY IN DRILLHOLE AM3103
DATE : Comp.30th APR.1986

GEOMIN GROUNDWATER INFORMATION AND EVALUATION SYSTEM

DRAWN BY	CHECKED BY	HORZ SCALE	VERT SCALE	FIGURE	PAGE
C.M.		1:NTS	1:407	1	2 of 2

DRILLHOLE: AM3206

LITHOLOGY [1,2] / COMPLETED CONSTRUCTION [2,3]	DETAILED DESCRIPTION	DURING DRILLING DEPTH	WATER LEVEL	WATER FLOW	COMMENT
	BROWN SILT WITH TRACE SAND. BROWN SILTY SAND WITH TRACE OF SILT. HEAVILY OXIDIZED MAFIC ROCK WITH SOME CLAY. VERY FINE GRAINED (APHANITIC) MAFIC ROCK WT LITTLE OXIDATION MAJOR ALTERATION TO CHLORITE NOTED BELOW 36M (50% CHLORITE).				TOTAL DEPTH= 91.0 M. SWL= 10.35M. FIRST WATER: 1.0L/s FROM 36.0 M. FINAL YIELD= 8.0L/s FROM 91.0 M. CAS. LENGTH= 18.0 M. STICK UP= 0.30 M. GEOPHYSICS: MAG. PUMP TEST: RATE: .44L/s. DURATION: 2640 MIN. MAX. D.DOWN: 0.64 M. WATER CHEM: TEMP.=25Deg. PH.= 7.42. EC.= 790mSm.
		36.0	1.0L/s	WATER	
	VERY FINE GRAINED MAFIC ROCK WITH 25-50% PINK QUARTZ, MAFICS CHLORITIZED (30-50% CHLORITE).				
		61.5		6.7	
	END OF HOLE.	91.0		8.0	

PLOT TITLE : HYDROGEOLOGIC LOG
FROM DEPTH : 0 m
TO DEPTH : 91 m

1,2,3,... NUMBERS REFER TO LITHOLOGIC NOTES

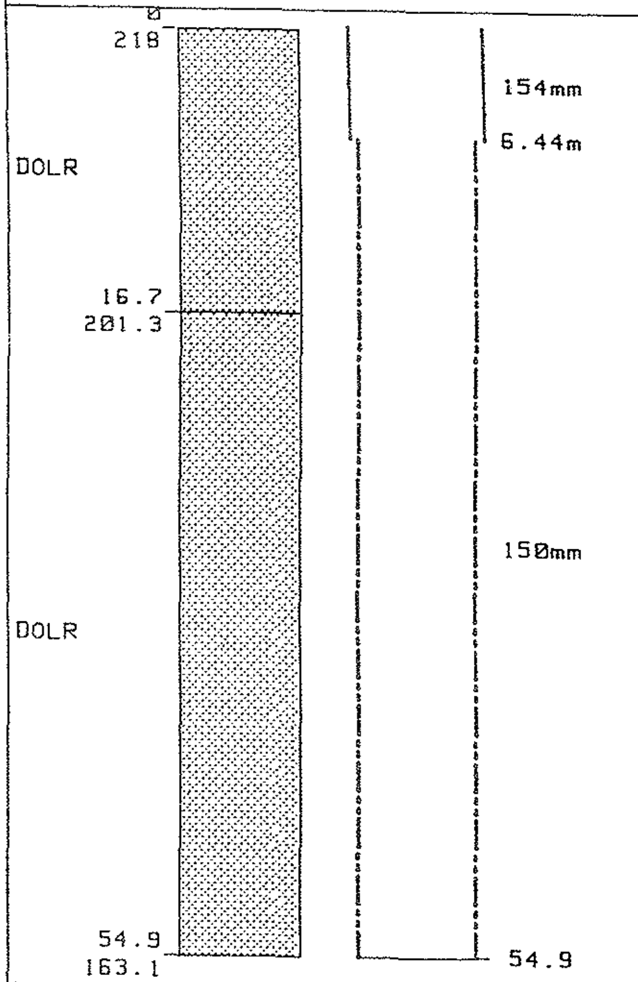
PROJECT : SWAZILAND GROUNDWATER SURVEY
STUDY : LITHILOGY IN DRILLHOLE AM3206
DATE : Comp. 6th JUN.1986

GEOMIN GROUNDWATER INFORMATION AND EVALUATION SYSTEM

DRAWN BY	CHECKED BY	HORZ SCALE	VERT SCALE	FIGURE	PAGE
C.M.		1:NTS	1:857	1	1

DRILLHOLE: AP3902

LITHOLOGY [1,2] — COMPLETED CONSTRUCTION [2,3]



DETAILED DESCRIPTION	DURING DRILLING DEPTH	WATER LEVEL	WATER FLOW	COMMENT
WEATHERED DOLERITE.				TOTAL DEPTH= 54.9 M. . SWL= 27.4 M. . FIRST WATER: 3.33L/s FROM 42.7 M. FINAL YIELD= 5.0L/s FROM 54.9 M. . CAS. LENGTH= 6.44 M. STICK UP= 0.24 M. . GEOPHYSICS: NONE. . PUMP TEST: RATES:1.11; AND 1.05L/s. DURATION: 2820 MINS. MAX. D.DOWN: 8.91 M. . WATER CHEM: TEMP.=23Deg. PH.= 8.5 EC.=2020mSm.
DARK GREY MEDIUM GRAINED DOLERITE.				
	42.7	3.33Ls	WATER	
	48.8		3.33	
END HOLE.	54.9		5.00	

PLOT TITLE : HYDROGEOLOGIC LOG
FROM DEPTH : 0 m
TO DEPTH : 54.9 m

1,2,3,... NUMBERS REFER TO LITHOLOGIC NOTES

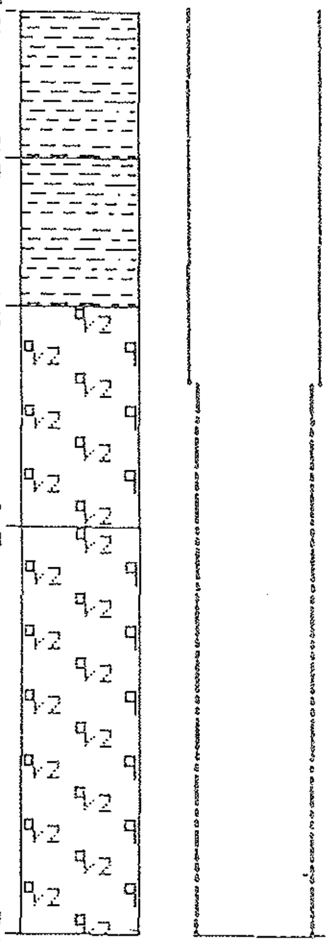
PROJECT : SWAZILAND GROUNDWATER SURVEY
STUDY : LITHOLOGY IN DRILLHOLE AP3902
DATE : Comp.20th AUG.1986

GEOMIN GROUNDWATER INFORMATION AND EVALUATION SYSTEM

DRAWN BY	CHECKED BY	HORZ SCALE	VERT SCALE	FIGURE	PAGE
C.M.		1:NTS	1:512	1	1

DRILLHOLE: AR0001

LITHOLOGY [1,2]	COMPLETED CONSTRUCTION [2,3]	DETAILED DESCRIPTION	DURING DRILLING DEPTH	WATER LEVEL	WATER FLOW
0 / 1512 CLAY 12.2		RED MICACEOUS CLAY.			
1499.8 CLAY 24.4	154mm	REDDISH BROWN MICACEOUS CLAY.			
1487.6 QZMN 42.7	30.62m	WEATHERED SCHIST WITH SOME QUARTZVEINLETS.	30.76	2.0L/s	WATER
			36.60		4.00
1469.3 QZMN 76.3 / 1435.7	150mm	DARK GREY FINE GRAINED SLIGHTLY FOLIATED SCHIST. SMALL QUARTZ VEIN .	42.70		4.00
			48.80		6.60
			54.90		6.60
			61.00		6.60
	76.3	END HOLE.	76.30		6.60



COMMENT

TOTAL DEPTH= 76.3 M.

SWL= 14.47M.

FIRST WATER: 2.0L/s FROM 30.76 M.
FINAL YIELD= 6.6L/s FROM 48.8 M.

CAS. LENGTH= 30.76 M.
STICK UP= 0.44 M.

GEOPHYSICS: NONE.

PUMP TEST:
RATE:2.0L/s.
DURATION: 1440 MIN.
MAX. D.DOWN: 4.99 M.

WATER CHEM:
TEMP.=14Deg.
PH.= 6.2
EC.= 132mSm.

PLOT TITLE : HYDROGEOLOGIC LOG
FROM DEPTH : 0 m
TO DEPTH : 76.3 m

PROJECT : SWAZILAND GROUNDWATER SURVEY
STUDY : LITHOLOGY IN DRILLHOLE AR0001
DATE : Comp.17th JUL.1990

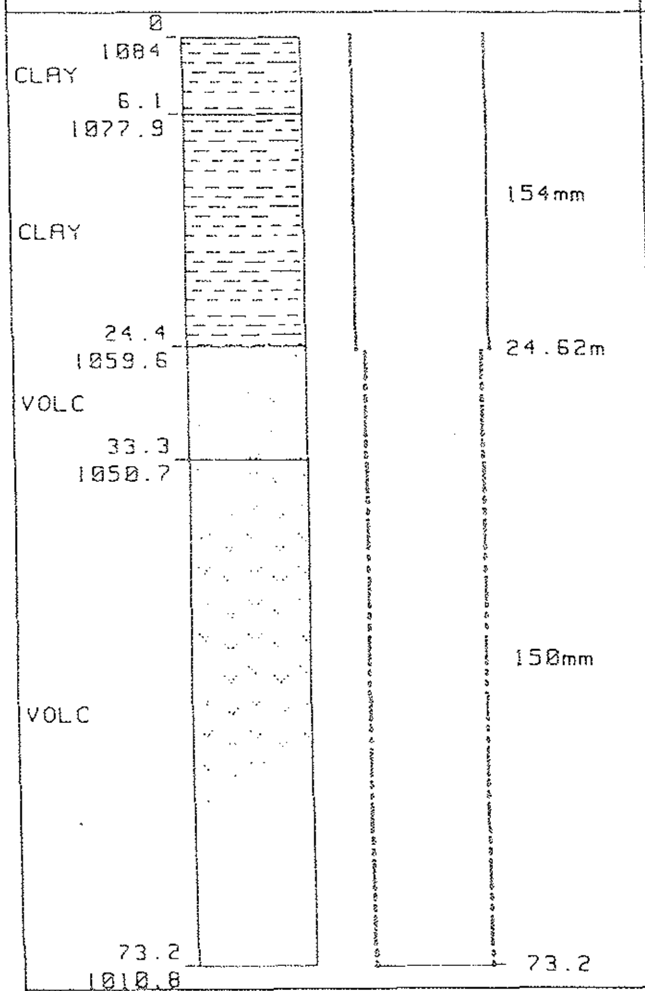
GEOMIN GROUNDWATER INFORMATION AND EVALUATION SYSTEM

DRAWN BY	CHECKED BY	HORZ SCALE	VERT SCALE	FIGURE	PAGE
C.M.		1:NTS	1:707		1

1,2,3,... NUMBERS REFER TO LITHOLOGIC NOTES

DRILLHOLE: AX1401

LITHOLOGY [1,2]	COMPLETED CONSTRUCTION [2,3]	DETAILED DESCRIPTION	DURING DRILLING: DEPTH	WATER LEVEL	WATER FLOW	COMMENT



DETAILED DESCRIPTION	DEPTH	WATER LEVEL	WATER FLOW
REDDISH BROWN CLAY.			
GREY CLAY.			
WEATHERED LAVA.	28.40	2.0L/s	WATER
	30.50		2.00
DARK GREEN MEDIUM GRAINED LAVA WITH SOME WHITE AMYGDALES AT 61.0 METRES.	36.60		6.60
	42.70		6.60
	48.80		6.60
	54.90		6.60
	61.00		6.60
	64.10		6.60
	67.10		6.60
END HOLE.	73.20		6.60

COMMENT

TOTAL DEPTH= 73.20 M.

SWL= 5.73 M.

FIRST WATER: 2.0L/s FROM 28.4 M.
FINAL YIELD= 6.6L/s FROM 36.6 M.

CAS. LENGTH= 24.62 M.
STICK UP= 0.43 M.

GEOPHYSICS: NONE.

PUMP TEST:
RATE:1.7L/s.
DURATION: 1440 MINS.
MAX. D.DOWN: 2.21 M.

WATER CHEM:
TEMP =18Deg.
PH.= 8.6
EC.= 200mSm.

PLOT TITLE : HYDROGEOLOGIC LOG
FROM DEPTH : 0 m
TO DEPTH : 73.2 m

1,2,3.... NUMBERS REFER TO LITHOLOGIC NOTES

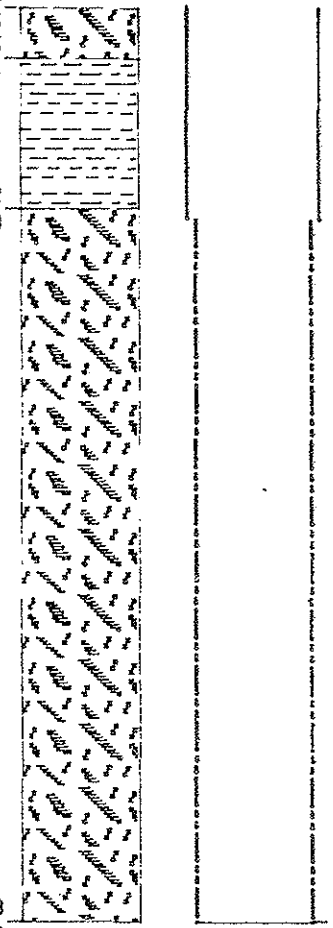
PROJECT : SWAZILAND GROUNDWATER SURVEY
STUDY : LITHOLOGY IN DRILLHOLE AX1401
DATE : Comp.16th AUG.1990

GEOMIN GROUNDWATER INFORMATION AND EVALUATION SYSTEM

DRAWN BY	CHECKED BY	HORZ SCALE	VERT SCALE	FIGURE	PAGE
C.M.		1:NTS	1:680	1	1

DRILLHOLE: BA2801

LITHOLOGY [1,2]	COMPLETED CONSTRUCTION [2,3]	DETAILED DESCRIPTION	DURING DRILLING DEPTH	WATER LEVEL	WATER FLOW	COMMENT
Ø GNSS 366 / 4.6 361.4 CLAY 18.2 / 347.8 GNSS 83.3 / 282.7	154mm 18.99m 150mm 83.3	WEATHERED AMPHIBOLITE. BROWN CLAY-SOIL, RICH IN HORNBLENDE. GREY, COARSE GRAINED AMPHIBOLITE CONSISTING OF HORNBLENDE AND FELSPAR, AND ALSO ROUND GRAINS OF QUARTZ AND SURROUNDED BY HORNBLENDE. END HOLE.	36.6 42.7 61.Ø 73.2 83.3	1.ØL/s	WATER 2.5 2.5 5.Ø 5.Ø	TOTAL DEPTH= 83.3 M. SWL= 3.51 M. FIRST WATER: 1.ØL/s FROM 36.6 M. FINAL YIELD= 5.ØL/s FROM 83.3 M. CAS. LENGTH= 18.99 M. STICK UP= Ø.3Ø M. GEOPHYSICS: NONE. PUMP TEST: NONE. WATER CHEM: PH.= 8.Ø EC.= 325mSm.



PLOT TITLE : HYDROGEOLOGIC LOG
FROM DEPTH : Ø m
TO DEPTH : 83.3 m

1,2,3,... NUMBERS REFER TO LITHOLOGIC NOTES

PROJECT : SWAZILAND GROUNDWATER SURVEY
STUDY : LITHOLOGY IN DRILLHOLE BA2801
DATE : Comp.1Øth FEB.1988

GEOMIN GROUNDWATER INFORMATION AND EVALUATION SYSTEM

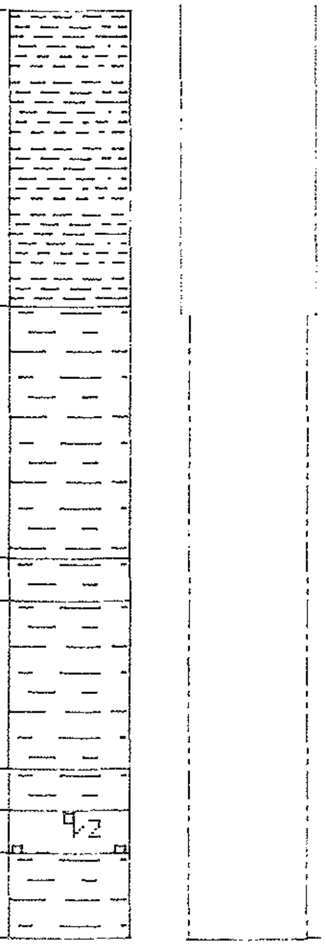
DRAWN BY	CHECKED BY	HORZ SCALE	VERT SCALE	FIGURE	PAGE
C.M.		1:NTS	1:778	1	1

DRILLHOLE: BC2701 | DURING DRILLING

DRILLHOLE: BC2701

LITHOLOGY [1,2]	Top depth (m)	Top elevation	Bottom depth (m)	Bottom elevation	DETAILED DESCRIPTION
CLAY	0	780	21.4	758.6	REDDISH BROWN CLAY.
SHAL	21.4	758.6	39.6	740.4	WEATHERED SLATE.
SHAL	39.6	740.4	42.7	737.3	FRESH DARK GREY SLATE.
SHAL	42.7	737.3	54.9	725.1	DEEPLY WEATHERED SHALE.
SHAL	54.9	725.1	57.9	722.1	FRESH GREY SLATE.
QZMN	57.9	722.1	61	719	WEATHERED QUARTZITE.
SHAL	61	719	67.1	712.9	FRESH GREY SLATE.
					END HOLE.

COMPLETED CONSTRUCTION [2,3]



DURING DRILLING

DEPTH	WATER LEVEL	WATER FLOW
30.50	5.0L/s	WATER
36.60		5.00
42.70		5.00
48.80		5.00
54.90		6.70
61.00		6.70

COMMENT

TOTAL DEPTH= 67.1 M.

SWL= 24.37M.

FIRST WATER: 5.0L/s FROM 30.5 M.

FINAL YIELD= 6.7 M.

CAS. LENGTH= 21.93 M.

STICK UP= 0.55 M.

GEOPHYSICS: NONE.

PUMP TEST: NONE.

WATER CHEM: NONE.

PLOT TITLE : HYDROGEOLOGIC LOG
FROM DEPTH : 0 m
TO DEPTH : 67.1 m

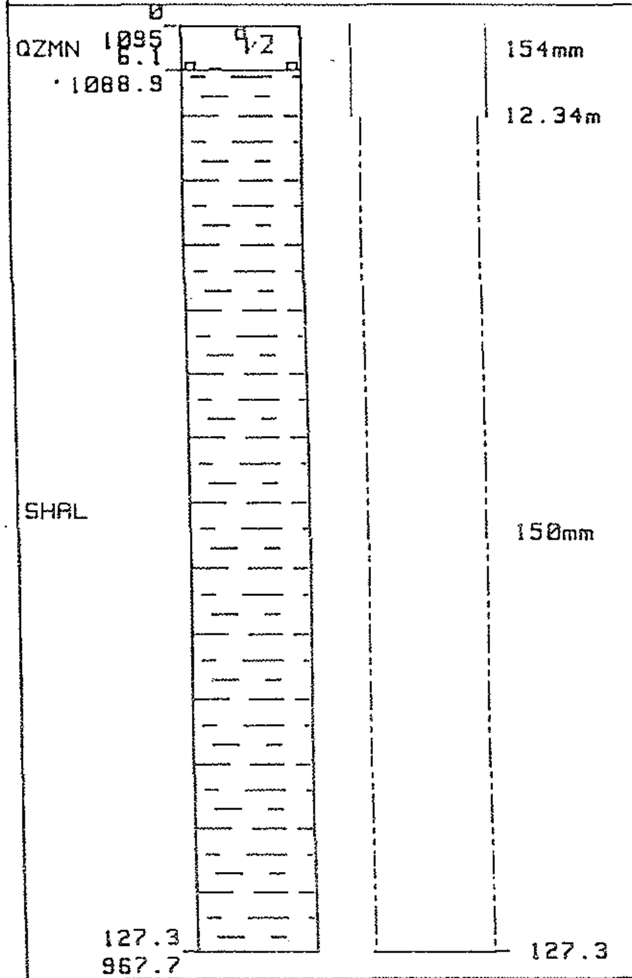
PROJECT : SWAZILAND GROUNDWATER SURVEY
STUDY : LITHOLOGY IN DRILLHOLE BC2701
DATE : Comp.27th NOV.1990

GEOMIN GROUNDWATER INFORMATION AND EVALUATION SYSTEM

DRAWN BY	CHECKED BY	HORZ SCALE	VERT SCALE	FIGURE	PAGE
C.M.		1:NTS	1:630	1	1

1,2,3,... NUMBERS REFER TO LITHOLOGIC NOTES

DRILLHOLE: BE0901

LITHOLOGY [1,2] / COMPLETED CONSTRUCTION [2,3]	DETAILED DESCRIPTION	DURING DRILLING DEPTH	WATER LEVEL	WATER FLOW	COMMENT
	WEATHERED QUARTZITE.				TOTAL DEPTH= 127.3 M.
	DARK SOFT CARBONACEOUS SHALE.				SWL= 1.51 M.
		18.30	2.0L/s	WATER	FIRST WATER: 2.0L/s FROM 18.3 M.
		24.40		2.00	FINAL YIELD= 4.0L/s FROM 127.3 M.
		30.50		2.00	CAS. LENGTH= 12.34 M. STICK UP= 0.38 M.
		36.60		2.00	GEOPHYSICS: RESISTIVITY.
		42.70		2.00	PUMP TEST: NONE.
		48.80		2.00	WATER CHEM: NONE.
		54.90		2.00	
		61.00		2.00	
		73.20		2.00	
		79.30		2.00	
		85.40		2.00	
		91.50		4.00	
		97.50		4.00	
		103.7		4.00	
		109.8		4.00	
		115.1		4.00	
		121.2		4.00	
	END HOLE.	127.3		4.00	

PLOT TITLE : HYDROGEOLOGIC LOG
FROM DEPTH : 0 m
TO DEPTH : 127.3 m

PROJECT : SWAZILAND GROUNDWATER SURVEY
STUDY : LITHOLOGY IN DRILLHOLE BE0901
DATE : Comp. 5th OCT.1990

GEOMIN GROUNDWATER INFORMATION AND EVALUATION SYSTEM

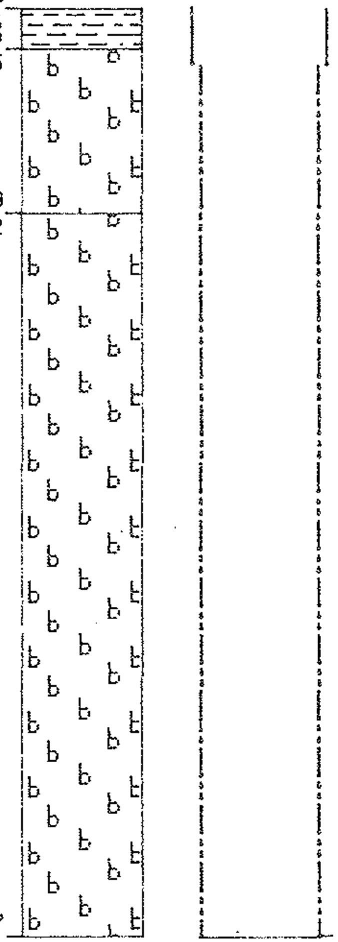
DRAWN BY	CHECKED BY	HORZ SCALE	VERT SCALE	FIGURE	PAGE
C.M.	[signature]	1:NTS	1:1184	1	1

1,2,3.... NUMBERS REFER TO LITHOLOGIC NOTES

DRILLHOLE: BL4601 | DURING DRILLING

DRILLHOLE: BL4601

LITHOLOGY [1,2]	COMPLETED CONSTRUCTION [2,3]	DETAILED DESCRIPTION	DURING DRILLING: DEPTH	DURING DRILLING: WATER LEVEL	DURING DRILLING: WATER FLOW	COMMENT
0 CLAY 254 / 4.5 249.5 BSLT 22.9 231.2 BSLT 103.7 150.3	154mm 6.1m 150mm 103.7	LIGHT BROWN CLAY SOIL. WEATHERED BASALT. DARK FINE GRAINED BASALT WITH SOME QUARTZ FILLED AMYGDALES AND OCCASIONAL IRON STAINING. END HOLE.	61.5 79.3 85.4 91.5 100.0	.50L/s	WATER 1.90 1.10 1.40 0.83	TOTAL DEPTH= 103.7 M. SWL= 28.6 M. FIRST WATER: 0.5L/s FROM 61.5 M. FINAL YIELD= 0.83L/s FROM 100.0 M. CAS. LENGTH= 6.1 M. STICK UP= 0.28 M. GEOPHYSICS: NONE. PUMP TEST: RATE:.5;.57; AND 0.54L/s. DURATION: 2879 MINS. MAX. D.DOWN: 24.61 M. WATER CHEM: PH.= 6.3 EC.=5005mSm.



PLOT TITLE : HYDROGEOLOGIC LOG
FROM DEPTH : 0 m
TO DEPTH : 103.7 m

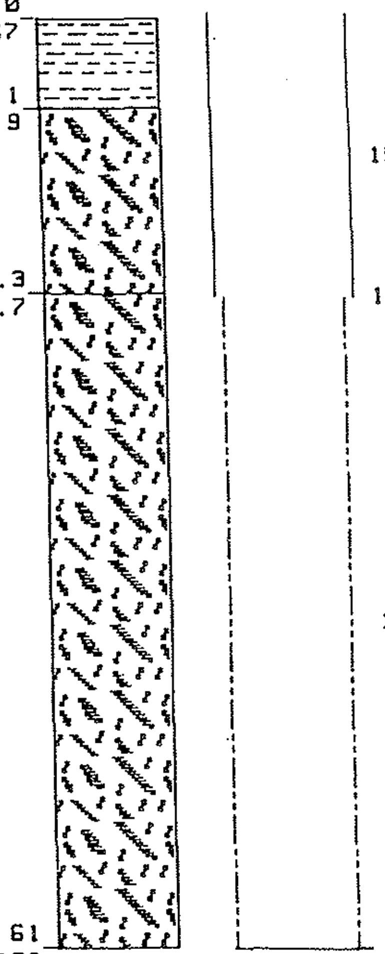
PROJECT : SWAZILAND GROUNDWATER SURVEY
STUDY : LITHOLOGY IN DRILLHOLE BL4601
DATE : Comp.25th FEB.1987

GEOMIN GROUNDWATER INFORMATION AND EVALUATION SYSTEM

DRAWN BY	CHECKED BY	HORZ SCALE	VERT SCALE	FIGURE	PAGE
C.M.		1:NTS	1:972	1	1

1,2,3,... NUMBERS REFER TO LITHOLOGIC NOTES

DRILLHOLE: BN1601



LITHOLOGY [1,2]	DETAILED DESCRIPTION	DURING DRILLING: DEPTH	WATER LEVEL	WATER FLOW	COMMENT
CLAY (0 – 6.1)	LT. BROWN CLAYEY SOIL				TOTAL DEPTH- 61.0m SWL = 18.90 FIRST WATER: 5.00 L/s FROM 48.8m FINAL YIELD: 5.00 L/s FROM 48.8m CAS. LENGTH- 18.51m STICK UP - 0.45m GEOPHYSICS: EM and MAG PUMP TEST: NONE
GNSS (6.1 – 18.3)	GREENISH GREY, WEATHERED GNEISS				
GNSS (18.3 – 61)	BAKED GNEISS, FRACTURED @ 30.5, 36.6m, AND 42.7m				
		48.80		5.00	
		54.90		5.00	
	END HOLE	61.00		5.00	

COMPLETED CONSTRUCTION [2,3]

PLOT TITLE : HYDROGEOLOGIC LOG
FROM DEPTH : 0 m
TO DEPTH : 61 m

PROJECT : SWAZILAND GROUNDWATER SURVEY
STUDY : LITHOLOGY IN DRILLHOLE BN1601
DATE : 11 Dec 1991

GEOMIN GROUNDWATER INFORMATION AND EVALUATION SYSTEM

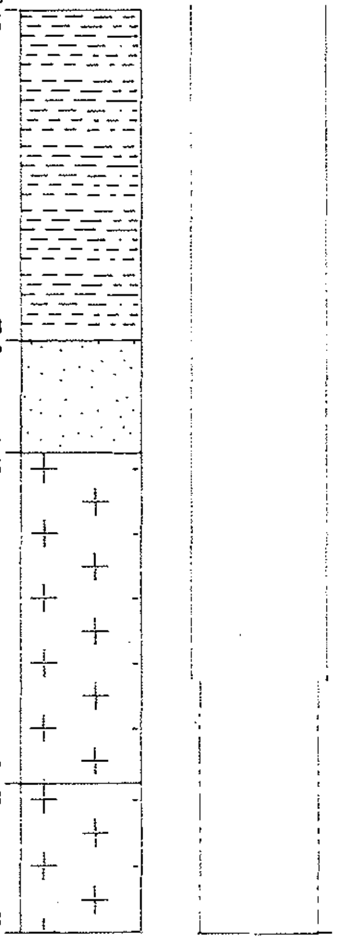
DRAWN BY	CHECKED BY	HORZ SCALE	VERT SCALE	FIGURE	PAGE
JWH		1:NTS	1:574	1	1

1,2,3,... NUMBERS REFER TO LITHOLOGIC NOTES

DRILLHOLE: BO2601

1,2,3,... NUMBERS REFER TO LITHOLOGIC NOTES	JWW		1:NTS	1:574	1	1

DRILLHOLE: B02601



Depth / Elevation	LITHOLOGY [1,2]	COMPLETED CONSTRUCTION [2,3]	DETAILED DESCRIPTION	COMMENT
0 / 765 – 18.3 / 746.7	CLAY	154mm	REDDISH BROWN CLAYEY SOIL.	TOTAL DEPTH= 50.8 M. . SWL= 11.14M. . FIRST WATER: 1.25L/s FROM 36.92 M. FINAL YIELD= 1.25L/s FROM 36.92 M. . CAS. LENGTH= 36.92 M. STICK UP= 0.45 M. . GEOPHYSICS: MAG. . PUMP TEST: PUMP DEPTH= 40 M. RATE: 1.0L/s DURATION: 1440 MINS. MAX. D.DOWN: 14.14 M. . WATER CHEM: TEMP.=24Deg. pH.= 7.6 Ec.= 286mSm.
18.3 / 746.7 – 24.4 / 740.6	SAND		LIGHT BROWN SANDY SOIL WITH ROCK FRAGMENTS.	
24.4 / 740.6 – 42.7 / 722.3	GRNT	36.92m	LIGHT GREY FRIABLE, WEATHERED GRANITE.	
42.7 / 722.3 – 50.8 / 714.2	GRNT	150mm	LIGHT GREY, HARD, FRESH COARSE GRAINED WITH ABUNDANT PINK FELDSPARS AND BIOTITE.	
50.8 / 714.2		50.8	END HOLE.	

PLOT TITLE : HYDROGEOLOGIC LOG
FROM DEPTH : 0 m
TO DEPTH : 50.8 m

PROJECT : SWAZILAND GROUNDWATER SURVEY
STUDY : LITHOLOGY IN DRILLHOLE B02601
DATE : Comp.31st JAN.1991

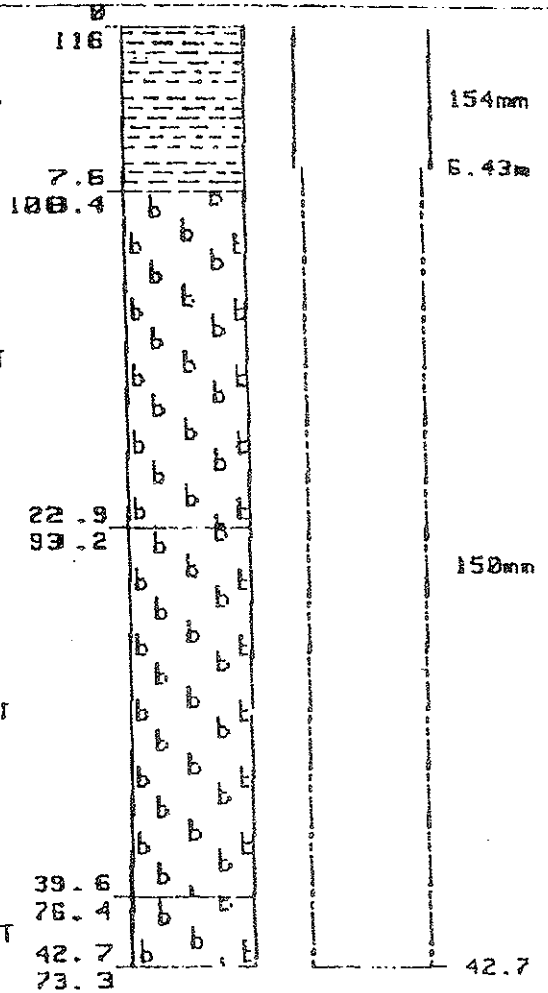
GEOMIN GROUNDWATER INFORMATION AND EVALUATION SYSTEM

DRAWN BY	CHECKED BY	HORZ SCALE	VERT SCALE	FIGURE	PAGE
C.M.		1:NTS	1:477	1	1

1,2,3,... NUMBERS REFER TO LITHOLOGIC NOTES

DRILLHOLE: BA4501

LITHOLOGY [1,2]	COMPLETED CONSTRUCTION [2,3]	DETAILED DESCRIPTION	COMMENT



DARK BROWN CLAY RICH SOIL.MOIST

WEATHERED IRON STAINED BASALT

FINE GREENISH GREY AMYGDALOIDAL BASALT SLIGHTLY WEATHERED.

HIGHLY WEATHERED IRON STAINED BASALT.

END HOLE.

COMMENT:

TOTAL DEPTH- 42.7 M.

SWL- 3.30 M.

FIRST WATER: 0.13L/s FROM 6.1 M.

FINAL YIELD- 10.0L/s FROM 18.3 M.

CAS. LENGTH- 6.43 M.

GEOPHYSICS: NONE.

PUMP TEST: NONE.

WATER CHEM: NONE.

PLOT TITLE : HYDROGEOLOGIC LOG
FROM DEPTH : 0 m
TO DEPTH : 42.7 m

PROJECT : SWAZILAND GROUNDWATER SURVEY
STUDY : LITHOLOGY IN DRILLHOLE BA4501
DATE : Comp.31st JAN.1987

GEOMIN GROUNDWATER INFORMATION AND EVALUATION SYSTEM

DRAWN BY	CHECKED BY	HORZ SCALE	VERT SCALE	FIGURE	PAGE
C.M.		1:NTS	1:398	1	1

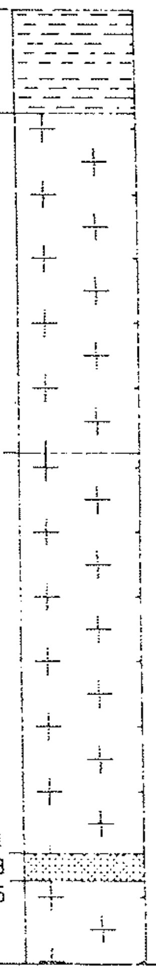
1,2,3.... NUMBERS REFER TO LITHOLOGIC NOTES

DRILLHOLE: K2802 | DURING DRILLING

1,2,3.... NUMBERS REFER TO LITHOLOGIC NOTES | C.M. | 1:NTS | 1:398 | 1 | 1

DRILLHOLE: K2802

LITHOLOGY [1,2]	COMPLETED CONSTRUCTION [2,3]	DETAILED DESCRIPTION	DURING DRILLING: DEPTH	DURING DRILLING: WATER LEVEL	DURING DRILLING: WATER FLOW	COMMENT
0 / 328 CLAY 7.6 / 320.4	154mm	GREY CLAY				STATIC WL= 19.79M, WELL YIELD=6.6L/S NO GEOPHYSICS RUN. TOTAL DEPTH=137.3M TOTAL CASING =7.3M. WATER QUALITY: TEMP.=20Deg. PH.=8.3 EC.=770 PUMPTEST WAS DONE FOR 32 MINUTES ONLY
GRNT		REDDISH-BROWN WEATHERED GRANITE SAMPLES WT DEPTHS 15.2M HAS DIABASE CHIPS				
32 / 296 GRNT		FRESH, GREY, MEDIUM GRAINED GRANITE WT ABOUT 15% BIOTITE NUMEROUS VEINLETS OF GREEN EPIDOTE COMMON THROUGHOUT THE FORMATION				
61 / 268 DOLR		DRK GREEN CRS GRAINED DIABASE				
265		FRESH GRANITE SIMILAR TO ABOVE				



PLOT TITLE : HYDROGEOLOGIC LOG
FROM DEPTH : 0 m
TO DEPTH : 69 m

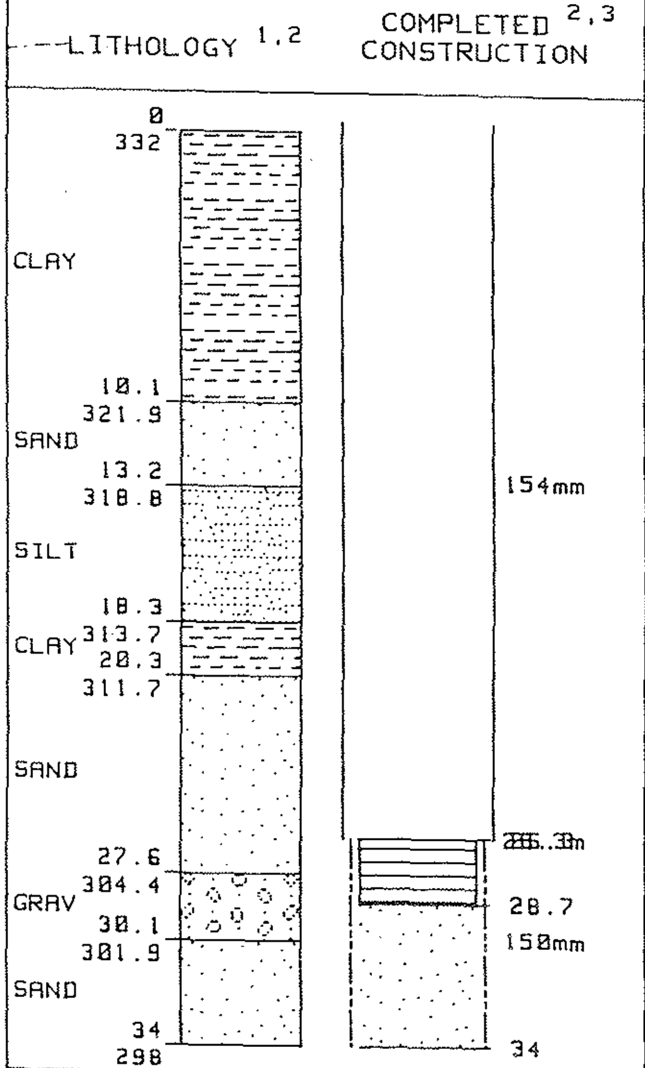
PROJECT : SWAZILAND GROUNDWATER SURVEY
STUDY : LITHOLOGY IN DRILLHOLE K2802
DATE : Comp.16th MAY,1989

GEOMIN GROUNDWATER INFORMATION AND EVALUATION SYSTEM

DRAWN BY	CHECKED BY	HORZ SCALE	VERT SCALE	FIGURE	PAGE
C.M.		1:NTS	1:623	1	1

1,2,3.... NUMBERS REFER TO LITHOLOGIC NOTES

DRILLHOLE: _03101



DETAILED DESCRIPTION	DURING DRILLING DEPTH	WATER LEVEL	WATER FLOW
REDDISH BROWN SOIL			
LIGHT BROWN MED TO COARSE SAND			
LIGHT BROWN SILTY CLAY			
DARK CLAY.			
COARSE TO MED SAND WT GRAVEL	20.4		WATER
	26.3		5.0
MED SAND TO COARSE GRAVEL	29.1		5.0
MED GRAINED WELL SORTED SAND			
END OF HOLE.	34.0		5.0

COMMENT

TOTAL DEPTH= 34.0 M.
FIRST WATER= FROM 20.4 M.
FINAL YIELD= 5.0L/s FROM 26.3 M.
SWL=12.05 M.
CASING LENGTH= 26.3 M.
STICK UP= 0.45 M.
GEOPHYSICS: RESISTIVITY.
PUMP TEST: RATE:5.0L/s. DURATION: 1440 MINS. MAX.D.DOWN: 4.15 M.
WATER QUALITY: TEMP.=22Deg. PH.=8.1 EC.= 700mSm.

PLOT TITLE : HYDROGEOLOGIC LOG
FROM DEPTH : 0 m
TO DEPTH : 34 m

PROJECT : SWAZILAND GROUNDWATER SURVEY
STUDY : LITHOLOGY IN DRILLHOLE _03101
DATE : Comp. 3rd APR.1989

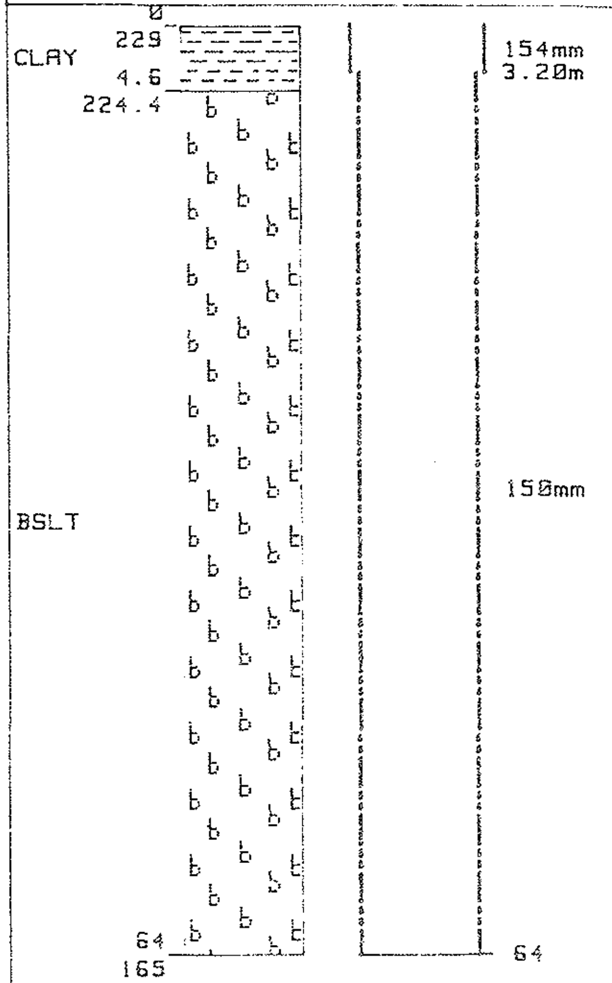
GEOMIN GROUNDWATER INFORMATION AND EVALUATION SYSTEM

DRAWN BY	CHECKED BY	HORZ SCALE	VERT SCALE	FIGURE	PAGE
C.M.		1:NTS	1:323	1	1

1,2,3.... NUMBERS REFER TO LITHOLOGIC NOTES

1,2,3.... NUMBERS REFER TO LITHOLOGIC NOTES | C.M. | | 1:NTS | 1:323 | 1 | 1

DRILLHOLE: _W4401

LITHOLOGY [1,2] / COMPLETED CONSTRUCTION [2,3]	DETAILED DESCRIPTION	DURING DRILLING DEPTH	WATER LEVEL	WATER FLOW	COMMENT
	BROWN CLAY SOIL. FRESH, GREENISH-GREY FINE GRAINED BASALT WITH SOME AMYGDALES. END HOLE.	18.00 30.50 48.80 64.00	0.7L/s	WATER 0.55 3.30 3.30	TOTAL DEPTH= 64.00 M. . SWL= 0.05 M. . FIRST WATER: 0.7L/s FROM 18.0 M. FINAL YIELD= 3.3L/s FROM 48.8 M. . CAS. LENGTH= 3.20 M. STICK UP= 0.25 M. . GEOPHYSICS: NONE. . PUMP TEST: NONE. . WATER CHEM: TEMP.=22Deg. PH.= 8.0 EC.=1710mSm.

PLOT TITLE : HYDROGEOLOGIC LOG
FROM DEPTH : 0 m
TO DEPTH : 64 m

PROJECT : SWAZILAND GROUNDWATER SURVEY
STUDY : LITHOLOGY IN DRILLHOLE _W4401
DATE : Comp.28th JUL.1988

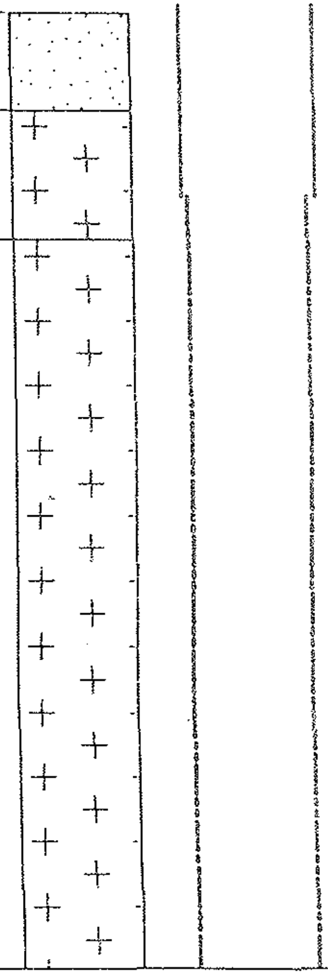
GEOMIN GROUNDWATER INFORMATION AND EVALUATION SYSTEM

DRAWN BY	CHECKED BY	HORZ SCALE	VERT SCALE	FIGURE	PAGE
C.M.		1:NTS	1:601	1	1

1,2,3,... NUMBERS REFER TO LITHOLOGIC NOTES

DRILLHOLE: _Z3001

LITHOLOGY [1,2]	COMPLETED CONSTRUCTION [2,3]	DETAILED DESCRIPTION	DURING DRILLING DEPTH	WATER LEVEL	WATER FLOW	COMMENT
0 / 351 SAND 4.6 / 346.4	154mm	BROWN SANDY SOIL.				TOTAL DEPTH= 83.3 M.
GRNT 10.7 / 340.3	8.67m	WEATHERED GRANITE.				SWL= 4.35 M.
GRNT		PALE COLOURED, COARSE GRAINED PORPHYRITIC GRANITE CONSISTING OF QUARTZ AND CHLORITIZED BIOTITE.				FIRST WATER: 0.71L/s FROM 21.3 M. FINAL YIELD= 6.75L/s FROM 83.3 M.
						CAS. LENGTH= 8.67 M. STICK UP= 0.35 M.
			21.30	.71L/s WATER		GEOPHYSICS: NONE.
						PUMP TEST: NONE.
			30.50		1.30	WATER CHEM: TEMP.=20Deg. PH.= 7.1 EC.=1050mSm.
			36.60		2.00	



PLOT TITLE : HYDROGEOLOGIC LOG
FROM DEPTH : 0 m
TO DEPTH : 45 m

PROJECT : SWAZILAND GROUNDWATER SURVEY
STUDY : LITHOLOGY IN DRILLHOLE _Z3001
DATE : Comp. 4th MAY,1988

GEOMIN GROUNDWATER INFORMATION AND EVALUATION SYSTEM

DRAWN BY	CHECKED BY	HORZ SCALE	VERT SCALE	FIGURE	PAGE
C.M.		1:NTS	1:400	1	1

1,2,3.... NUMBERS REFER TO LITHOLOGIC NOTES

DRILLHOLE: _X0801 DURING DRILLING

DRILLHOLE: _X0801

LITHOLOGY [1,2]	COMPLETED CONSTRUCTION [2,3]	DETAILED DESCRIPTION	DURING DRILLING: DEPTH	WATER LEVEL	WATER FLOW	COMMENT
0 / 1369 CLAY 12.2		LT BROWN CLAYEY SOIL				TOTAL DEPTH= 79.3 M. FIRST WATER FROM 42.7 M. FINAL YIELD= 6.7L/s FROM 67.1 M. SWL= 7.19 M. CASING LENGTH= 43.2 M. STICK UP= 0.45 M. GEOPHYSICS: NONE. PUMPTEST: RATE:2.0L/s. DURATION: 1440 MINS. MAX D.DOWN: 14.75 M. WATER QUALITY: TEMP.=22Deg. PH.= 5.9 EC.= 330mSm.
1356.8 CLAY 15.2		DEEPLY RED,CLAYEY SOIL				
1353.8 CLAY 18.3		LIGHT BROWN CLAYEY SOIL				
1350.7 SHST 21.3	154mm	LT GREY,DEEPLY WEATHERED SCHIST				
1347.7 SHST		GREENISH GREY SLIGHTLY WEATHERED TALC SCHIST.				

PLOT TITLE : HYDROGEOLOGIC LOG
FROM DEPTH : 0 m
TO DEPTH : 40.5 m

1,2,3,... NUMBERS REFER TO LITHOLOGIC NOTES

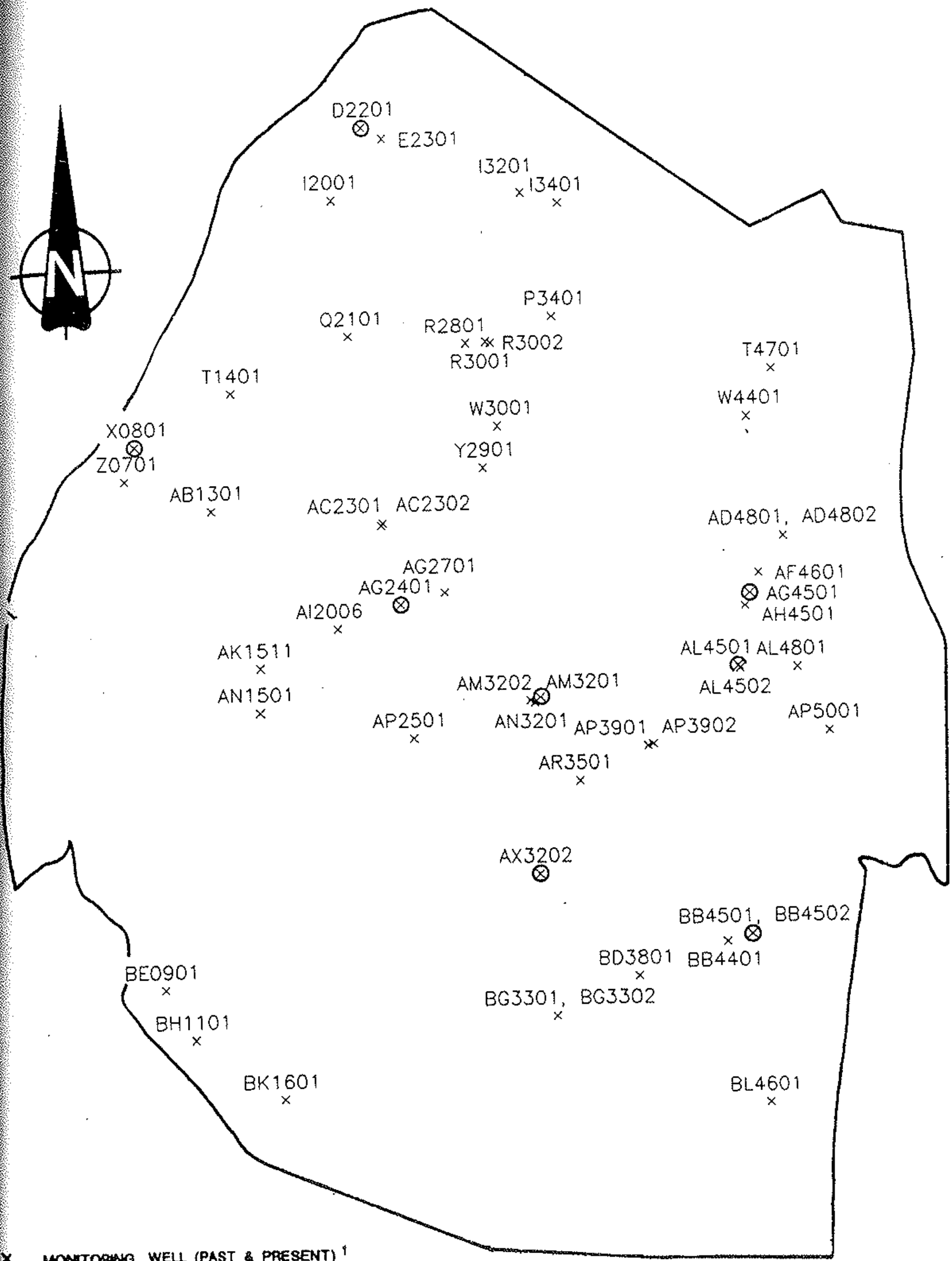
PROJECT : SWAZILAND GROUNDWATER SURVEY
STUDY : LITHOLOGY IN DRILLHOLE _X0801
DATE : Comp.17th OCT.1989

GEOMIN GROUNDWATER INFORMATION AND EVALUATION SYSTEM

DRAWN BY	CHECKED BY	HORZ SCALE	VERT SCALE	FIGURE	PAGE
C.M.		1:NTS	1:371	1	1

APPENDIX F

HYDROGRAPHS OF GROUNDWATER LEVELS



× MONITORING WELL (PAST & PRESENT) [1] WATER LEVEL

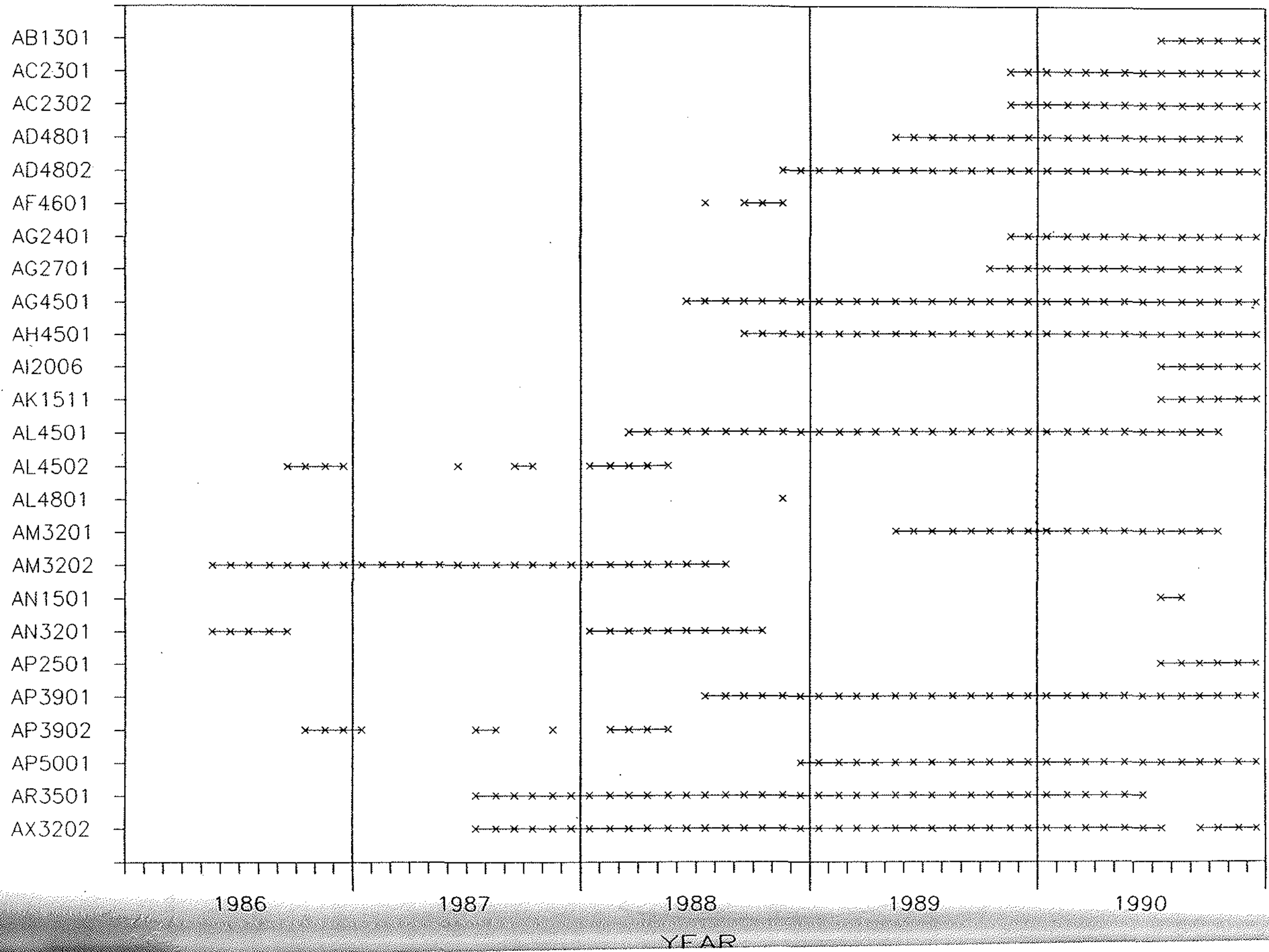
⊗ HYDROGRAPH PLOT AVAILABLE

NOTE: 1. FOR MONITORING RECORD SUMMARY SEE FOLLOWING PAGES.

MONITORING WELL LOCATION PLAN

FIGURE: F1

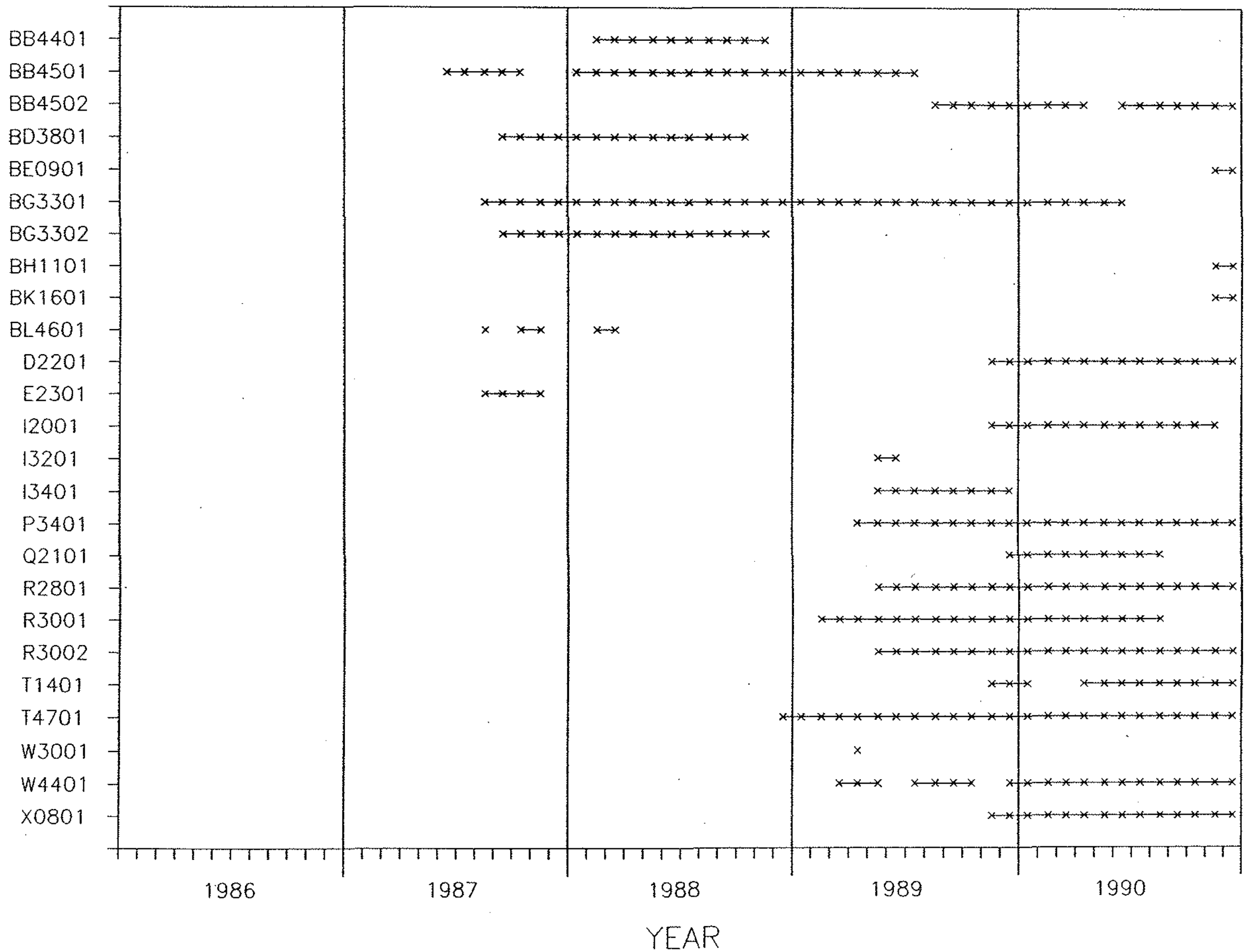
MONITORING WELL RECORD SUMMARY



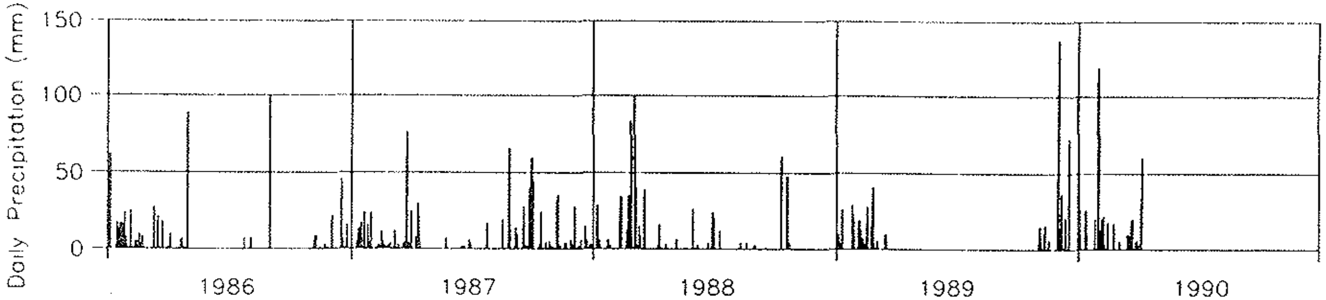
WELL

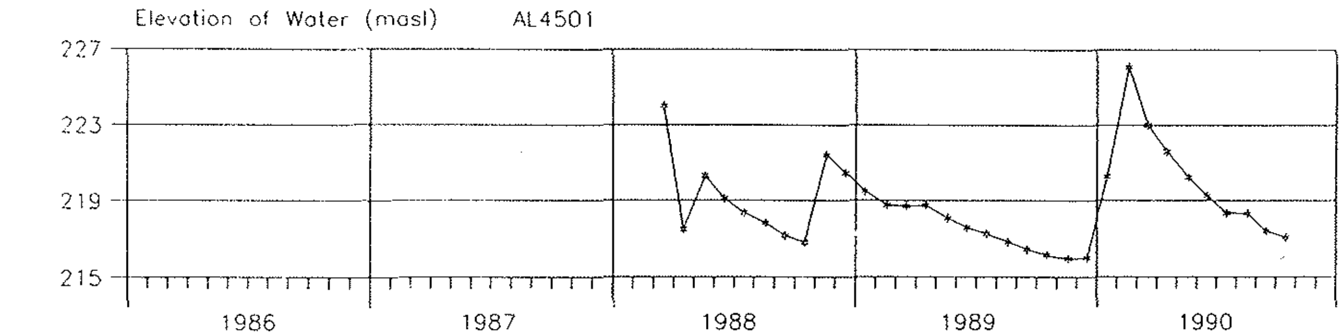
MONITORING WELL RECORD SUMMARY (cont'd)

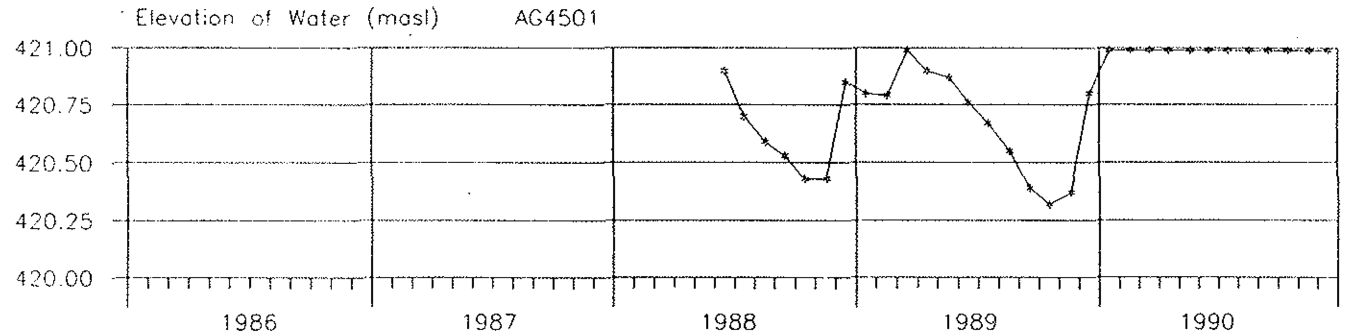
MONITORING WELL RECORD SUMMARY (cont'd)



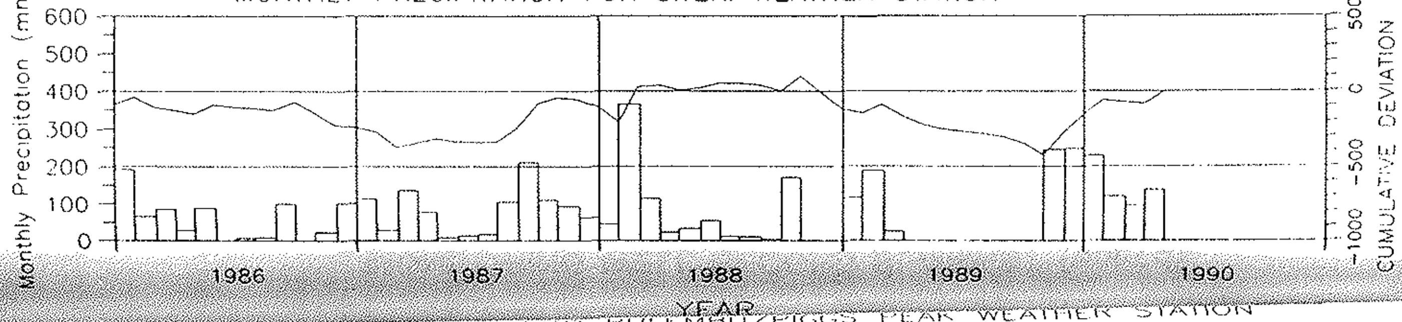
DAILY PRECIPITATION FOR SITEKI WEATHER STATION





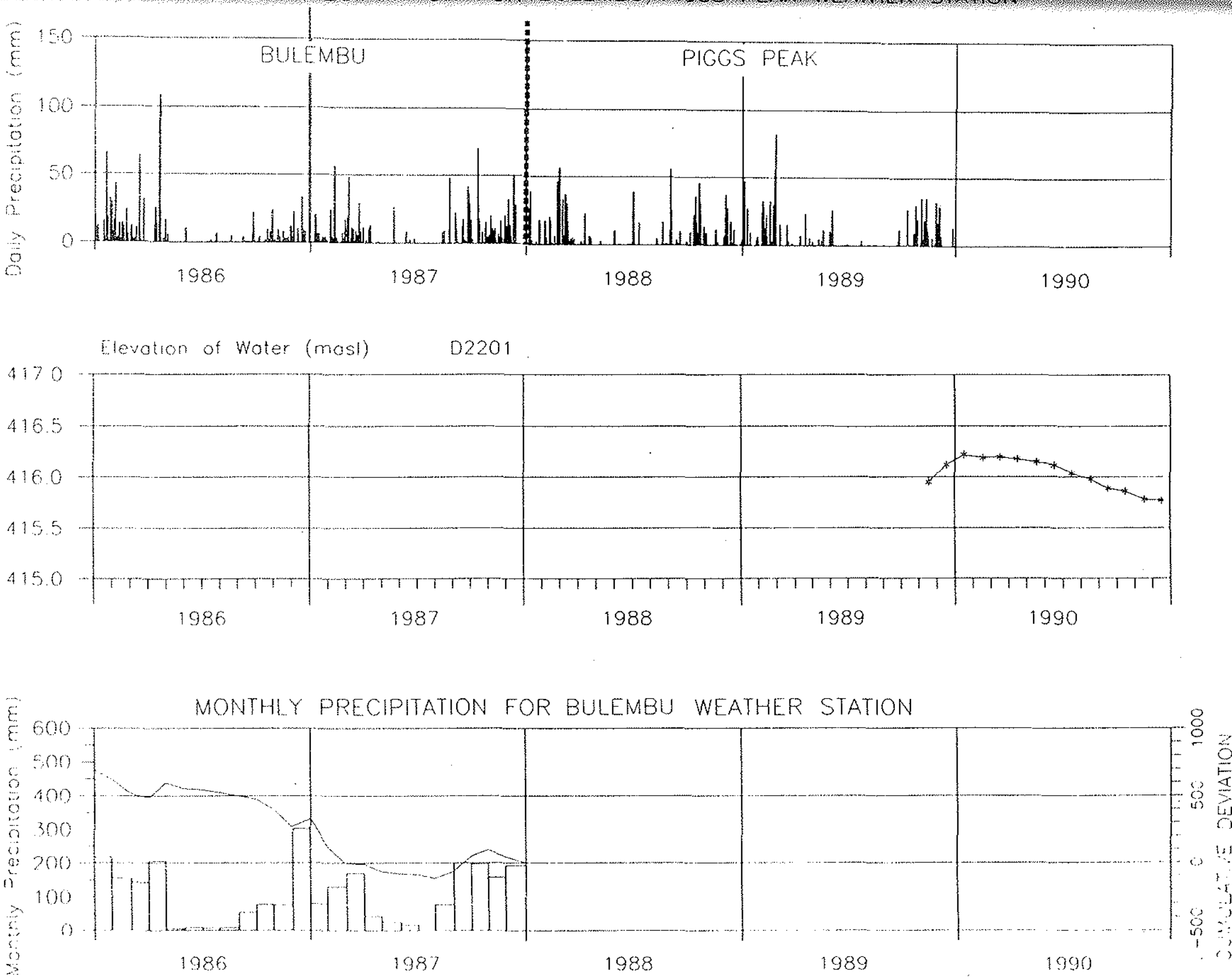


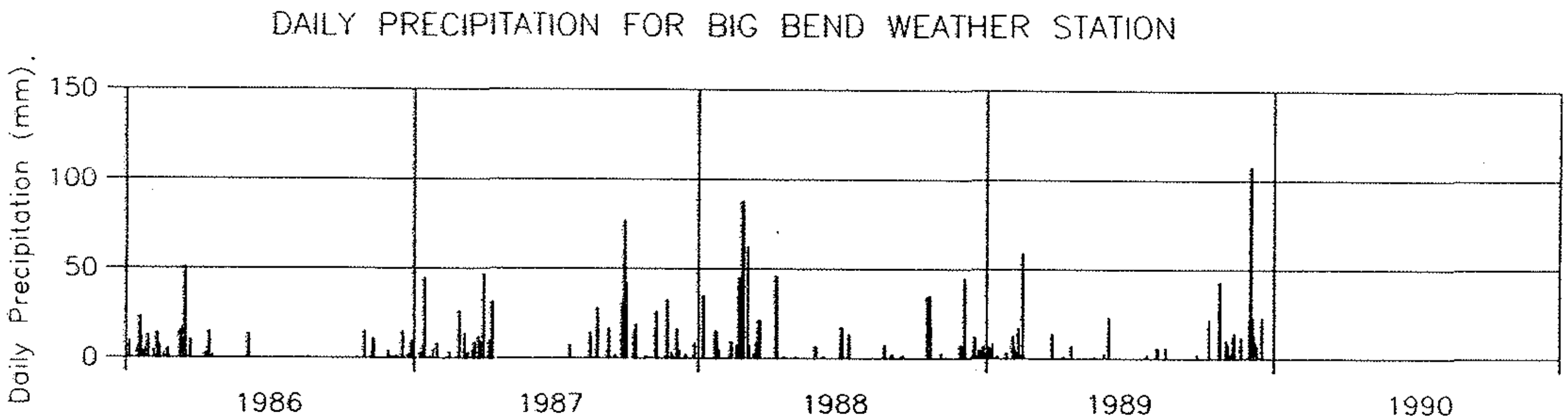
MONTHLY PRECIPITATION FOR SITEKI WEATHER STATION

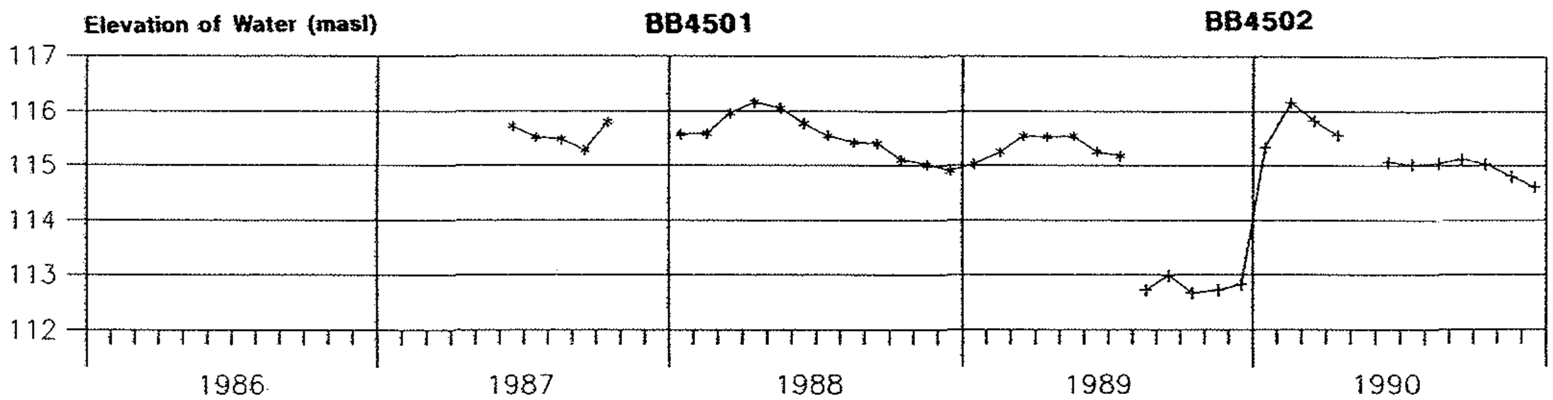


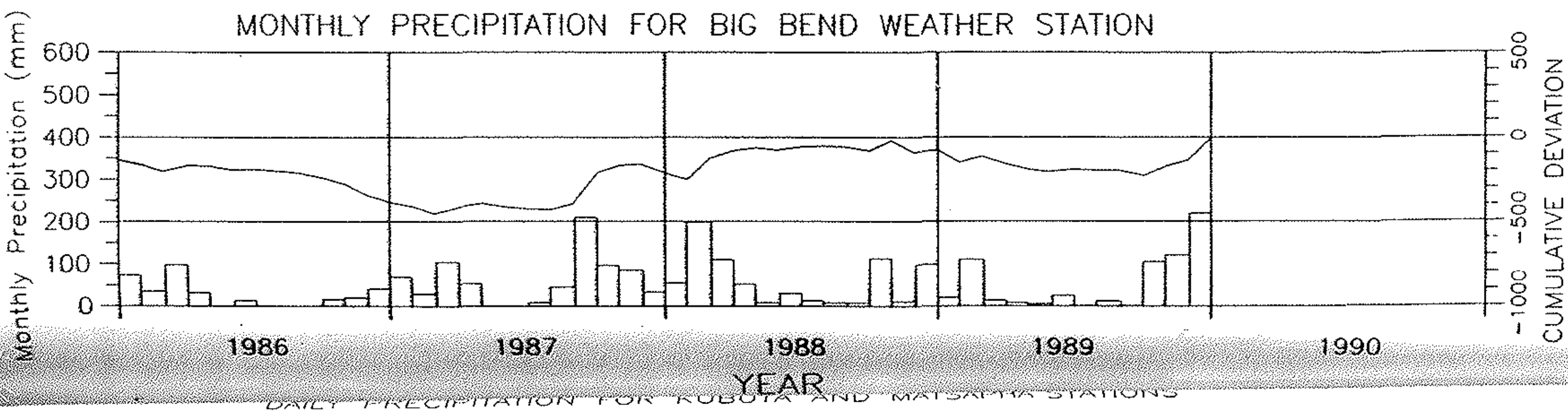
DAILY PRECIPITATION FOR BULEMBU/PIGGS PEAK WEATHER STATION

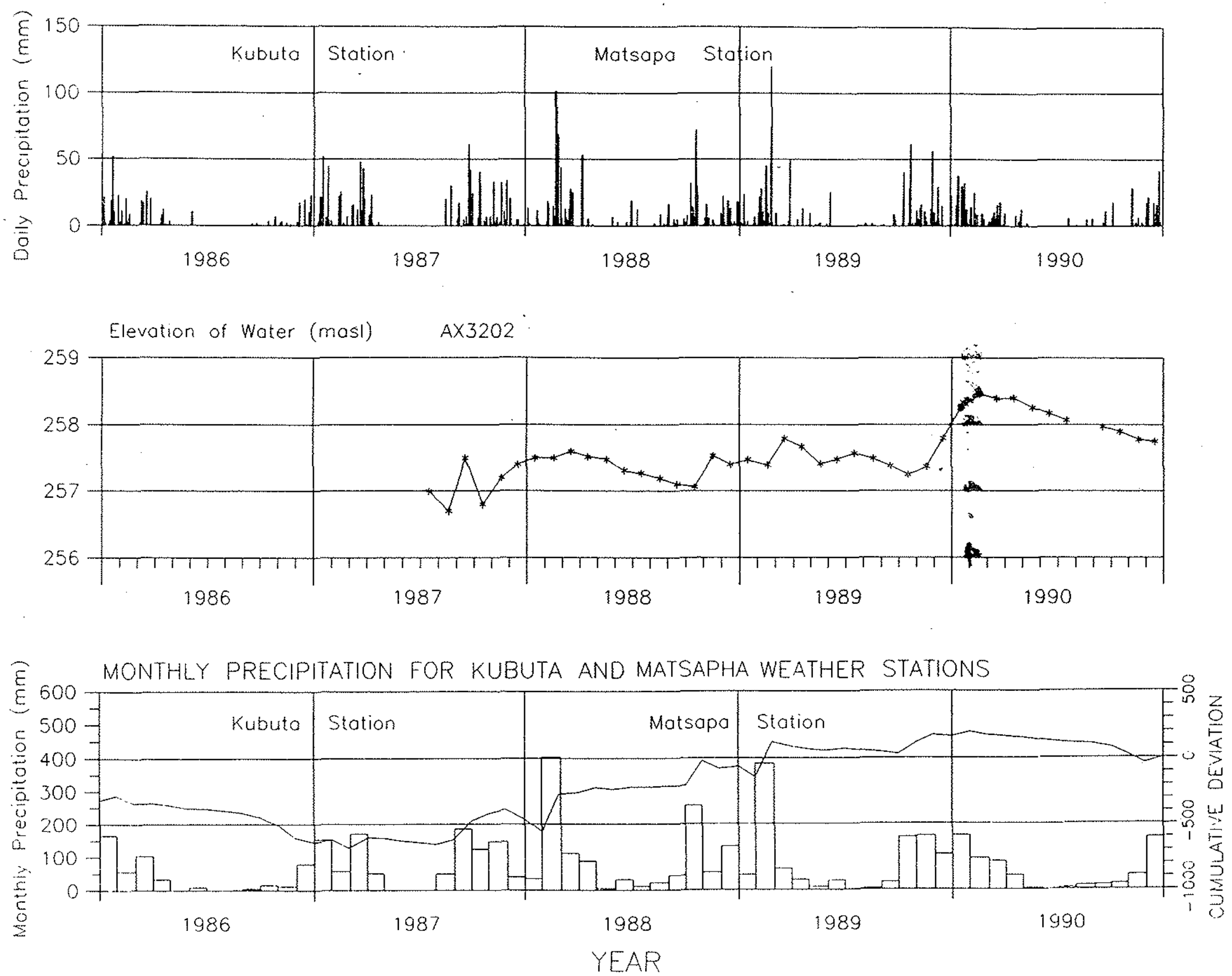
DAILY PRECIPITATION FOR BULEMBU/PIGGS PEAK WEATHER STATION




DAILY PRECIPITATION FOR BIG BEND WEATHER STATION
Daily Precipitation (mm).
150
100
50
0
1986
1987
1988
1989
1990

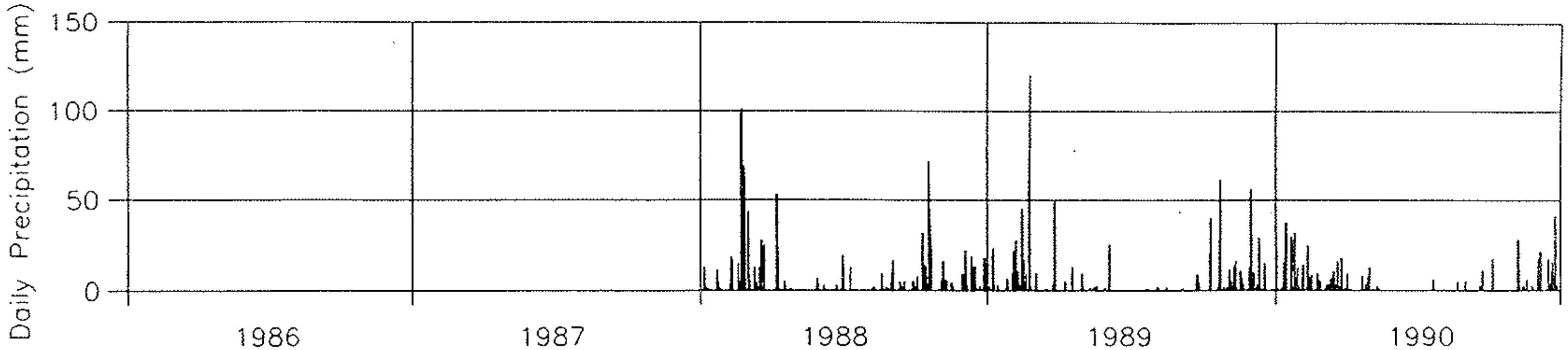

Elevation of Water (masl)
BB4501
BB4502
117
116
115
114
113
112
1986
1987
1988
1989
1990

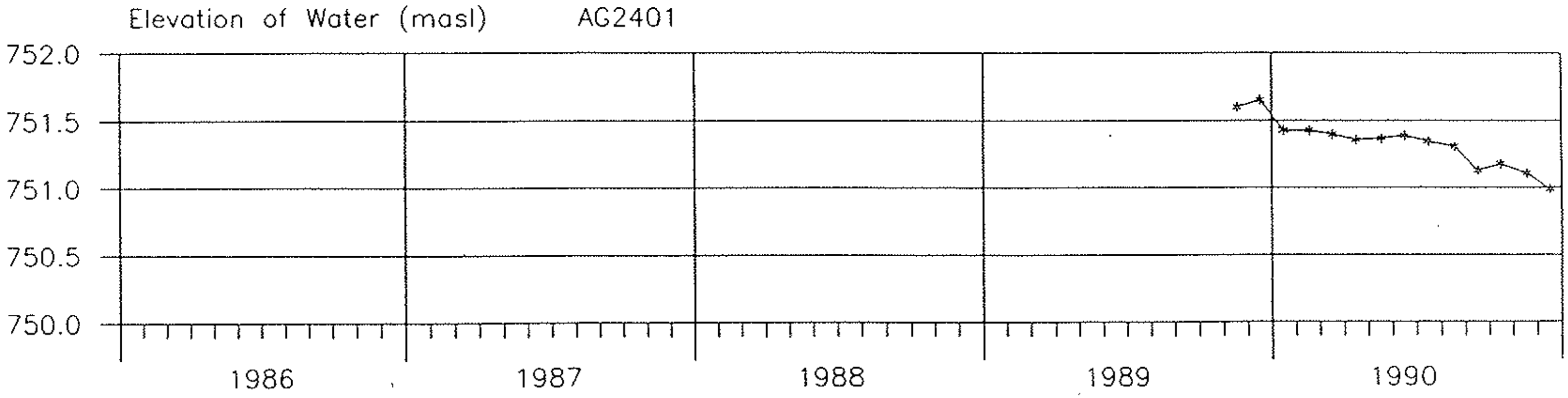

MONTHLY PRECIPITATION FOR BIG BEND WEATHER STATION
Monthly Precipitation (mm)
600
500
400
300
200
100
0
CUMULATIVE DEVIATION
500
0
-500
-1000
1986
1987
1988
1989
1990
YEAR



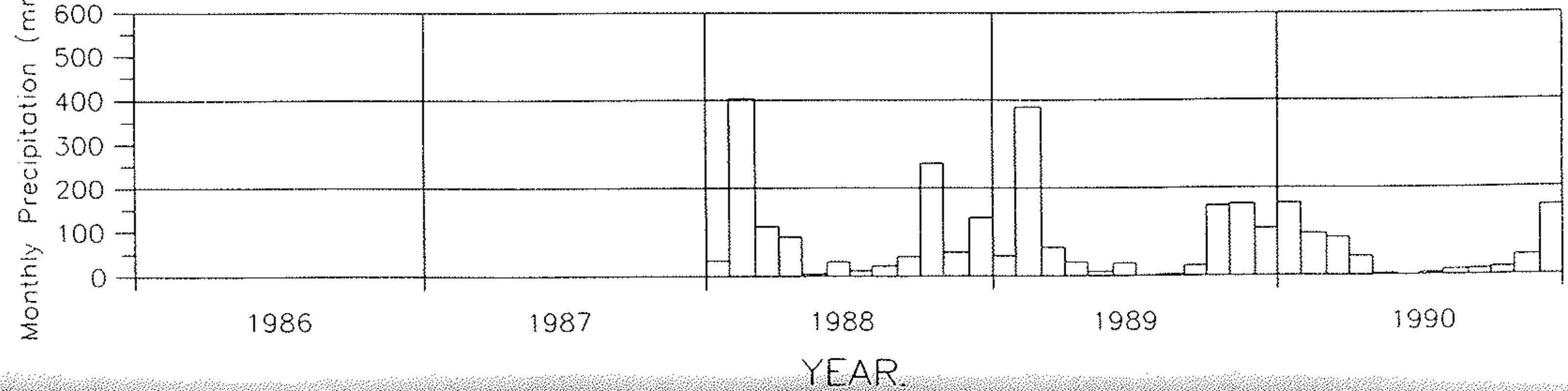
Daily Precipitation (mm)
150
100
50
0
Kubuta Station
Matsapa Station
1986
1987
1988
1989
1990
Elevation of Water (masl) AX3202
259
258
257
256
1986
1987
1988
1989
1990
MONTHLY PRECIPITATION FOR KUBUTA AND MATSAPHA WEATHER STATIONS
Monthly Precipitation (mm)
600
500
400
300
200
100
0
Kubuta Station
Matsapa Station
500
0
-500
-1000
CUMULATIVE DEVIATION
1986
1987
1988
1989
1990
YEAR

DAILY PRECIPITATION FOR MATSAPHA WEATHER STATION



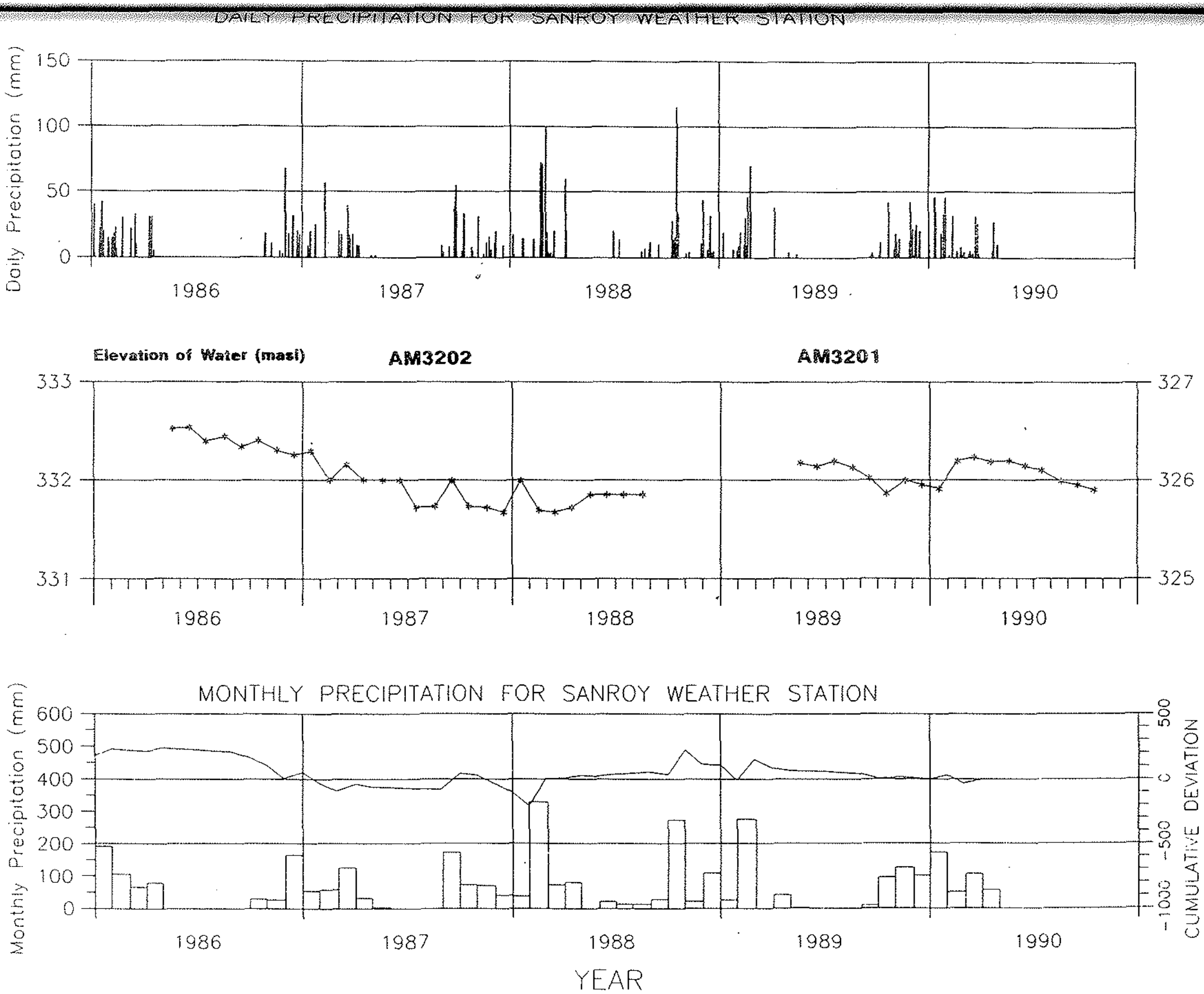


MONTHLY PRECIPITATION FOR MATSAPHA WEATHER STATION



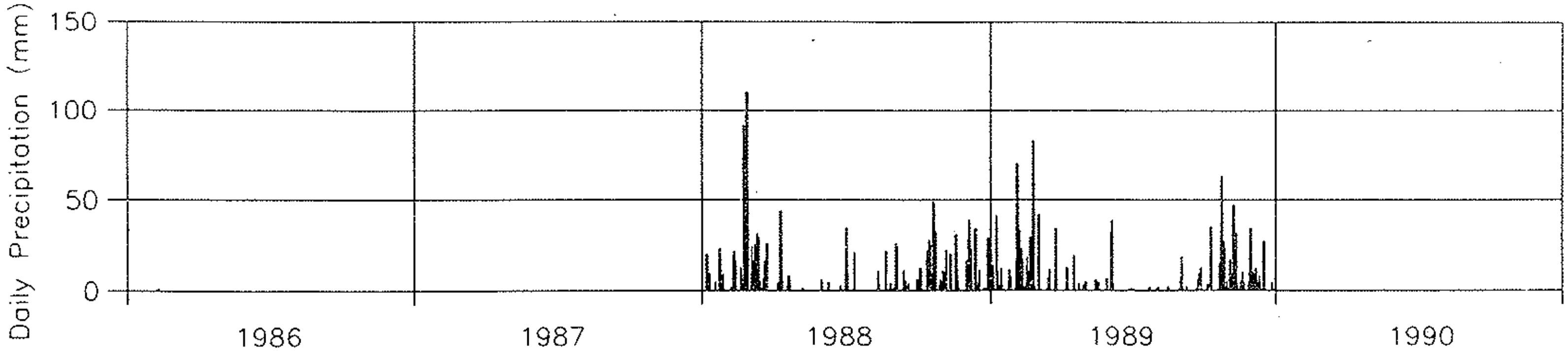
DAILY PRECIPITATION FOR SANROY WEATHER STATION

YEAR.

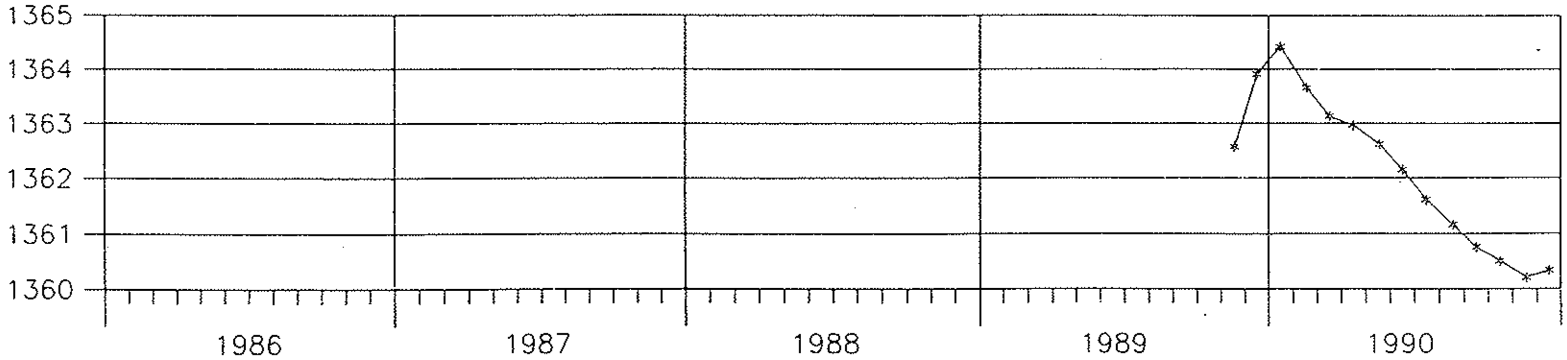


DAILY PRECIPITATION FOR SANROY WEATHER STATION
Daily Precipitation (mm)
150
100
50
0
1986
1987
1988
1989
1990
Elevation of Water (masl)
AM3202
AM3201
333
332
331
327
326
325
1986
1987
1988
1989
1990
MONTHLY PRECIPITATION FOR SANROY WEATHER STATION
Monthly Precipitation (mm)
600
500
400
300
200
100
0
CUMULATIVE DEVIATION
500
0
-500
-1000
1986
1987
1988
1989
1990
YEAR

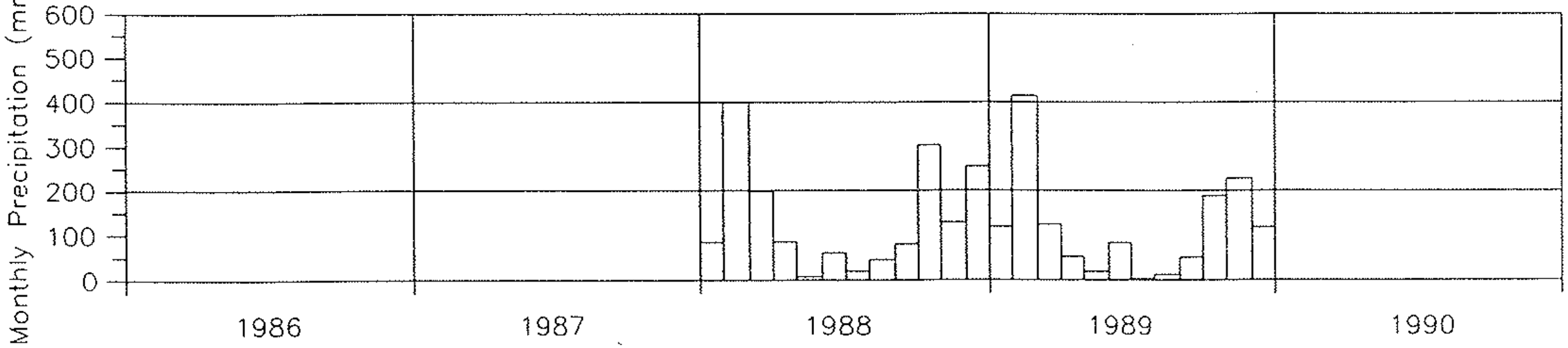
DAILY PRECIPITATION FOR MBABANE WEATHER STATION



Elevation of Water (masl) X0801



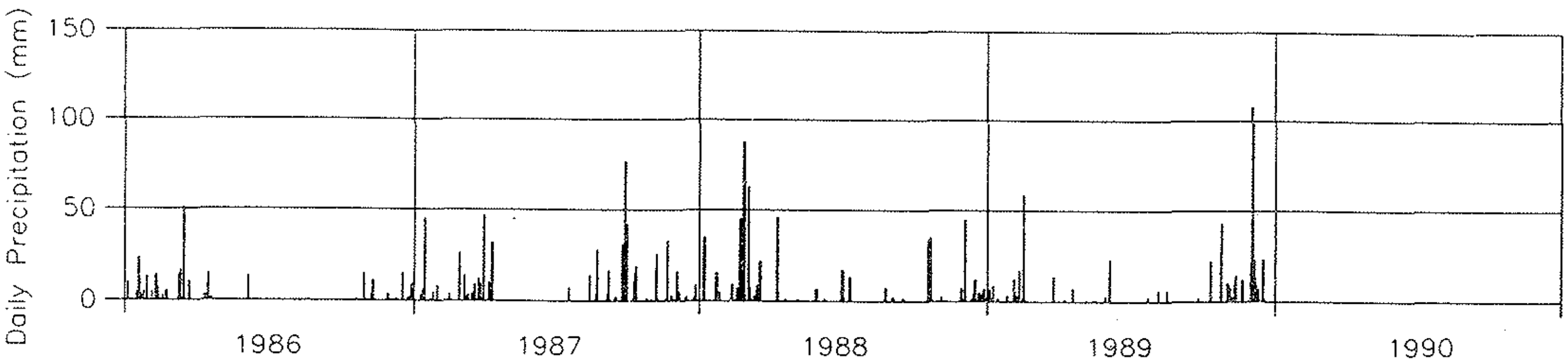
MONTHLY PRECIPITATION FOR MBABANE WEATHER STATION



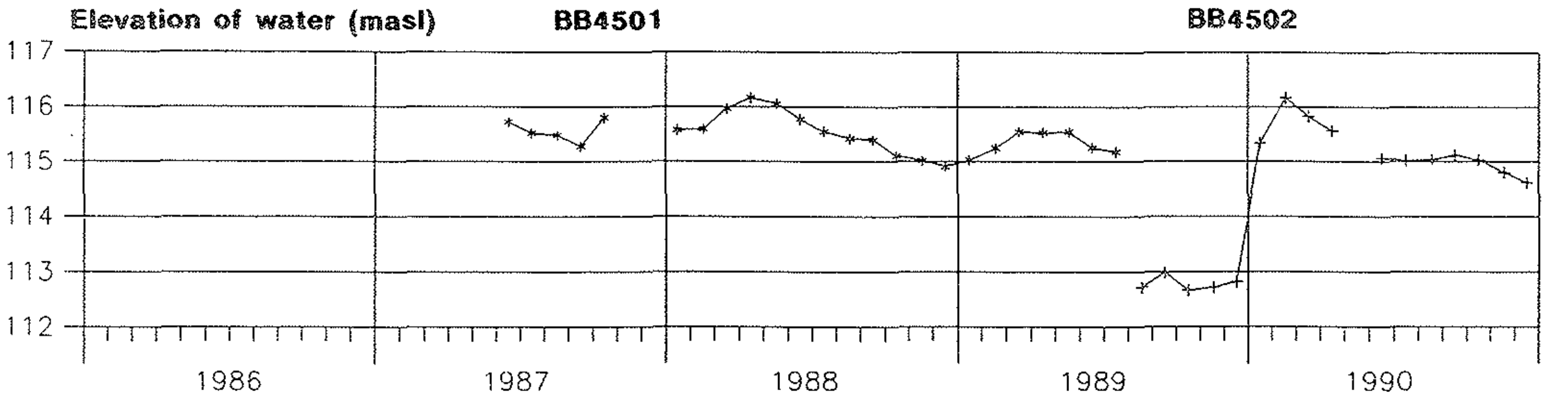
YEAR

DAILY PRECIPITATION FOR BIG BEND WEATHER STATION

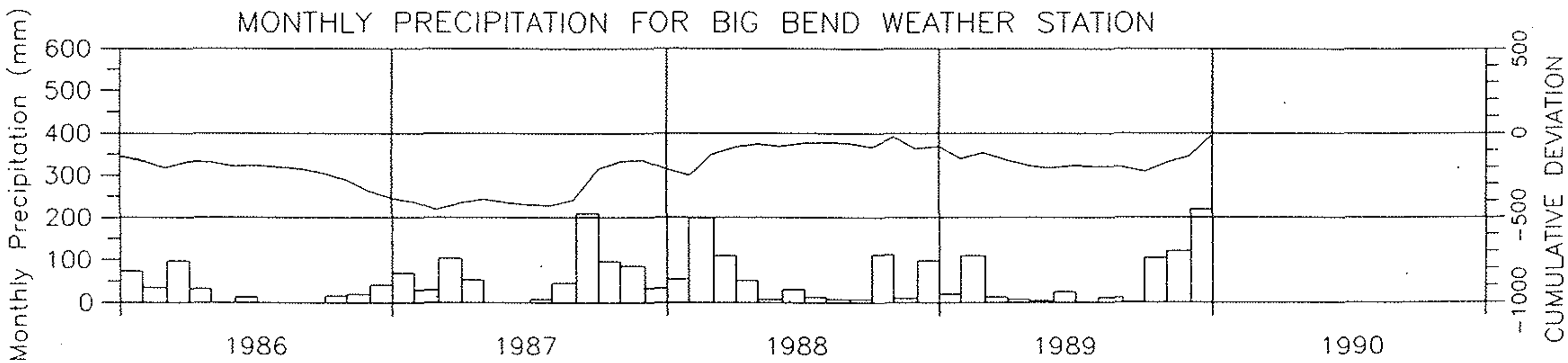
YEAR



Daily Precipitation (mm)
150
100
50
0
1986
1987
1988
1989
1990



Elevation of water (masl)
BB4501
BB4502
117
116
115
114
113
112
1986
1987
1988
1989
1990



MONTHLY PRECIPITATION FOR BIG BEND WEATHER STATION
Monthly Precipitation (mm)
600
500
400
300
200
100
0
CUMULATIVE DEVIATION
500
0
-500
-1000
1986
1987
1988
1989
1990

YEAR

APPENDIX G

ESTIMATES OF GROUNDWATER RECHARGE

APPENDIX: G

ESTIMATION OF GROUNDWATER RECHARGE

G.1 PRECIPITATION AND SOIL INFILTRATION MODEL

The following is a description of a computer spreadsheet model used for estimating groundwater recharge from a precipitation record, and assuming a variety of soil properties. The model calculates the soil moisture on a daily basis, after considering demands for potential evapotranspiration (PET). When the soil moisture content exceeds the field capacity, the excess water is contributed to groundwater recharge. The basic moisture flow paths in the model are illustrated in Fig. G1. The series of calculations and conditions made are displayed on the flow chart of Fig. G2.

Initially, runoff losses are subtracted from the precipitation events prior to infiltration. Next, the PET losses are calculated, using the Thornthwaite method. Thornthwaite estimates of PET are derived from the monthly temperature values. These values are adjusted for monthly variations in sunshine duration applied for the latitude of 25 S. These are then converted to daily values by dividing the monthly value by the number of days in the month.

If the amount of precipitation after runoff is sufficient to supply for PET losses, then there can be an excess to contribute to the soil moisture. This moisture excess is considered infiltration. If the precipitation was insufficient to supply PET demands, then the remainder must be extracted from the soil moisture to make up for the deficit. Reductions in soil moisture are limited to the wilting point value.

Soil moisture is calculated on the basis of the previous day's moisture content, subtracting the previous day's groundwater contributions and adding any of the present day's infiltration. Groundwater contributions only occur if the soil moisture is greater than the field capacity. The volume of groundwater contribution is not allowed to exceed the limit of the vertical gradient and the hydraulic conductivity.

This model calculates the total annual groundwater recharge as the sum of all daily groundwater contributions. This sum is expressed as a percentage of the total rainfall over that period. Due to the generally low soil moisture levels, only larger precipitation events result in groundwater contributions. The remaining infiltration is either wholly used for PET demands, or create fluctuations in soil moisture between the wilting point and field capacity.

EXAMPLE FOR: BIG BEND STATION

The following parameters were considered as reasonable for soils in Swaziland:

Precipitation: October 1, 1986 to September 30, 1988

Hydraulic conductivity:	1 X 10(-6) m/s
Vertical hydraulic gradient:	0.1 m/m
Runoff coefficient:	0.20
Thickness:	500mm
Field Capacity:	100mm (20%)
Wilting Point:	6.55mm (3.6%)

These assumptions resulted in a groundwater contribution of 3.6% of the precipitation per year. The wilting point is estimated as the average annual soil moisture. This value is derived from the monthly post-runoff precipitation and subtracting the monthly PET estimate. It is assumed that, in this part of the model, PET only occurs on days with rain. The monthly PET estimate is then calculated as the product of the daily

Thornthwaite PET and the number of days with rain.

G.2 MODEL SENSITIVITY

Many of the assumed values for soil properties assumed can vary by several orders of magnitude. In addition, the assumption that all Swaziland soils fit the assumptions used may seem questionable. However, it has been found from the use of independent models and experience that these assumption are reasonable. While soils deviating from these condition will certainly exist, the values used here are believed to probably represent an average condition.

The following is an explanation of the sensitivity of this model to variations in its individual parameters. All variables except the one under discussion are the same as the values given for Big Bend station.

HYDRAULIC CONDUCTIVITY (K)

An increase in the hydraulic conductivity results in an increase in groundwater recharge. The model limits recharge rates by the ability of soil to transmit water. Beyond a certain point, this maximum recharge rate will exceed the infiltration rate, and further increases in recharge will not occur.

K (m/s)	GROUNDWATER (% of P)
1 X 10(-4)	5.7
1 X 10(-5)	5.7
1 X 10(-6)	3.6
1 X 10(-7)	0.4

HYDRAULIC GRADIENT (I)

Hydraulic gradient affects the ability of soil to transmit water in the same way as hydraulic conductivity. As such, increases gradient cause increases in groundwater contributions.

i (m/m)	GROUNDWATER (% P)
1.0	5.7
0.1	3.6
0.01	0.4

RUNOFF COEFFICIENT

As the runoff coefficient decreases, a greater proportion of rainfall infiltrates into the soil, promoting higher soil moisture levels.

R (% P)	GROUNDWATER (% P)
0.01	18.5
0.10	14.7
0.15	12.3
0.20	3.6
0.25	2.4

SOIL THICKNESS

As soil thickens, there exists a greater capacity to hold moisture. At a certain thickness, infiltration will never cause the soil moisture to exceed field capacity, and no groundwater contributions will be made.

T (mm)	GROUNDWATER (% of P)
750	0
500	3.6
250	10.9

FIELD CAPACITY

Field capacity acts as a threshold, below which there is no groundwater contribution. As this value increases, higher soil moisture contents are required to make groundwater contributions. At a certain point, no contributions are made as the soil can absorb all infiltration.

FIELD CAPACITY (% of soil volume)	GROUNDWATER (% of P)
0.10	10.9
0.15	7.5
0.20	3.6
0.25	1.4
0.30	0.0

WILTING POINT

The wilting point is the minimum level of moisture in the soil. At higher values, the magnitude of additions of moisture required to reach field capacity is lower. As such, increases in wilting point increase recharge.

WILTING POINT (% of soil volume)	GROUNDWATER (% of P)
0.4	3.2
1.2	3.5
2.0	3.9
3.0	4.5
4.0	12.7

G.3 RECHARGE ESTIMATION FROM WATER LEVELS

Another method for calculating groundwater recharge is to assume annual changes in groundwater levels are due solely to local recharge. Annual changes to groundwater levels occur because of seasonal differences in precipitation. Two parameters must be estimated: the volume of groundwater involved in the annual change, and the volume of precipitation delivered to the area.

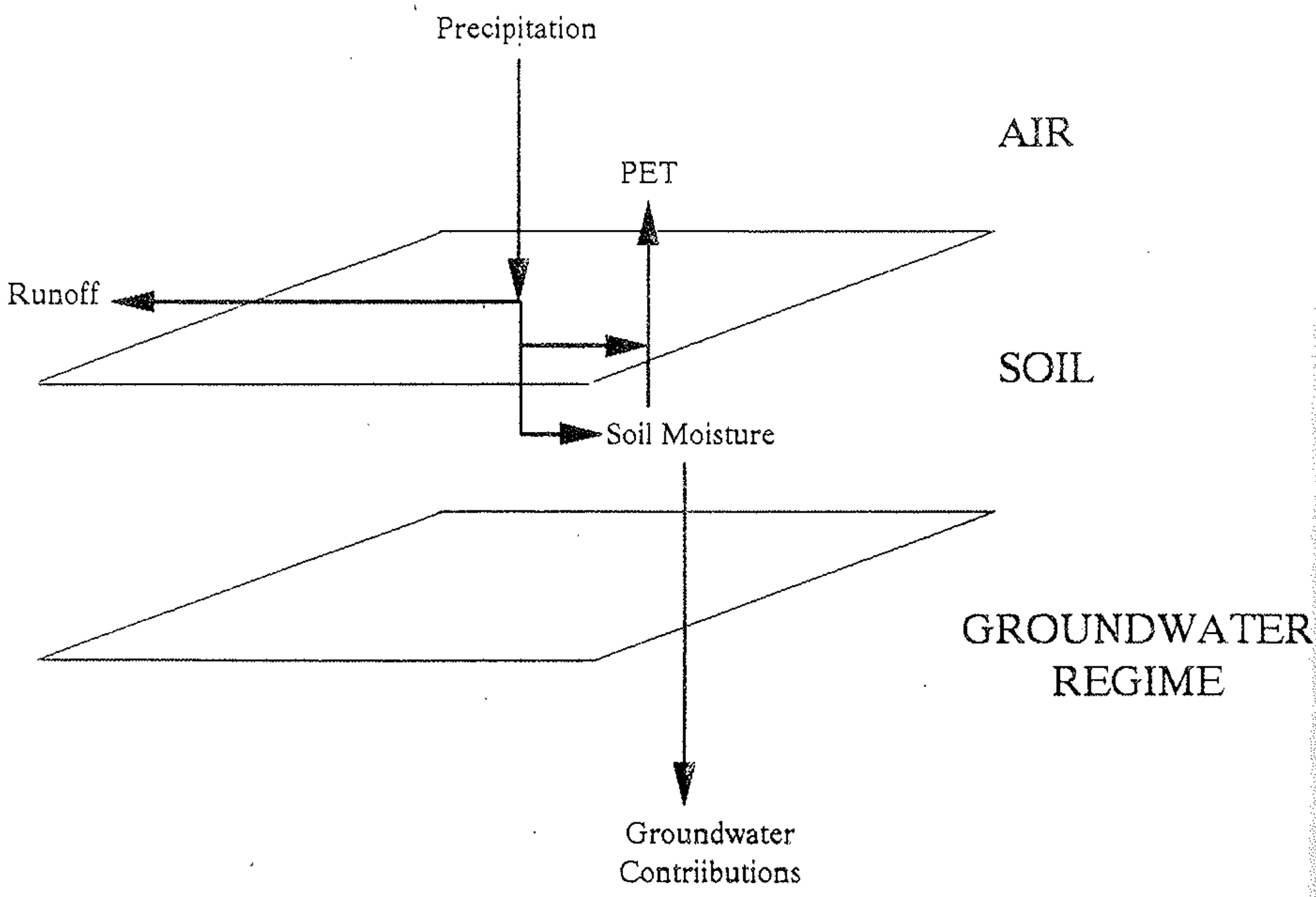
For a given well, calculations are made over an area that represents the local groundwater flow domain. For this study, this consisted of a one metre wide strip, extending across the valley. The width of the valley was determined from a topographic cross-section perpendicular to the valley axis.

The volume of groundwater can be obtained using a storativity based calculation. The magnitude of change is the difference from the minimum to the maximum groundwater levels observed over a one year period. The area extends across the valley. Storativity values are assumed.

It has been established from experience that recharge does not generally occur in the innermost third of a valley. As such, the area that can receive precipitation recharge is considered as two-thirds the area of the strip across the valley. This area, multiplied by the annual depth of precipitation, produces the volume of precipitation available. After both calculations are made, the percentage of recharge volume to precipitation volume is straightforward.

Calculations were made for five boreholes where relatively long records groundwater levels were available and results are provided on (Table VII). These boreholes are X0801, AG2401, BB4501, AX3202, and AL4501. Boreholes were selected on the basis of having at least one representative record from each of the Highveld, Middleveld, and Lowveld regions. Valley widths were obtained from topographic maps. Groundwater level changes were derived from the records in the year given. Precipitation records were taken from the long term value for the nearest local station from which they were available.

As can be seen, the results derived from the daily precipitation model and the groundwater level calculation are comparable. Most values for groundwater contributions in both models were usually under 5% of the total precipitation, despite widely varying locations and geological conditions.



THORNWAITE POTENTIAL EVAPOTRANSPIRATION MODEL

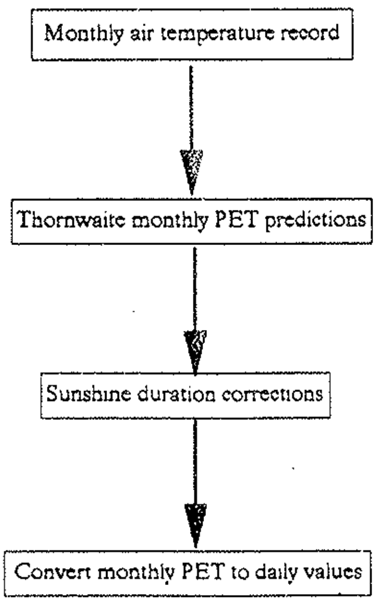
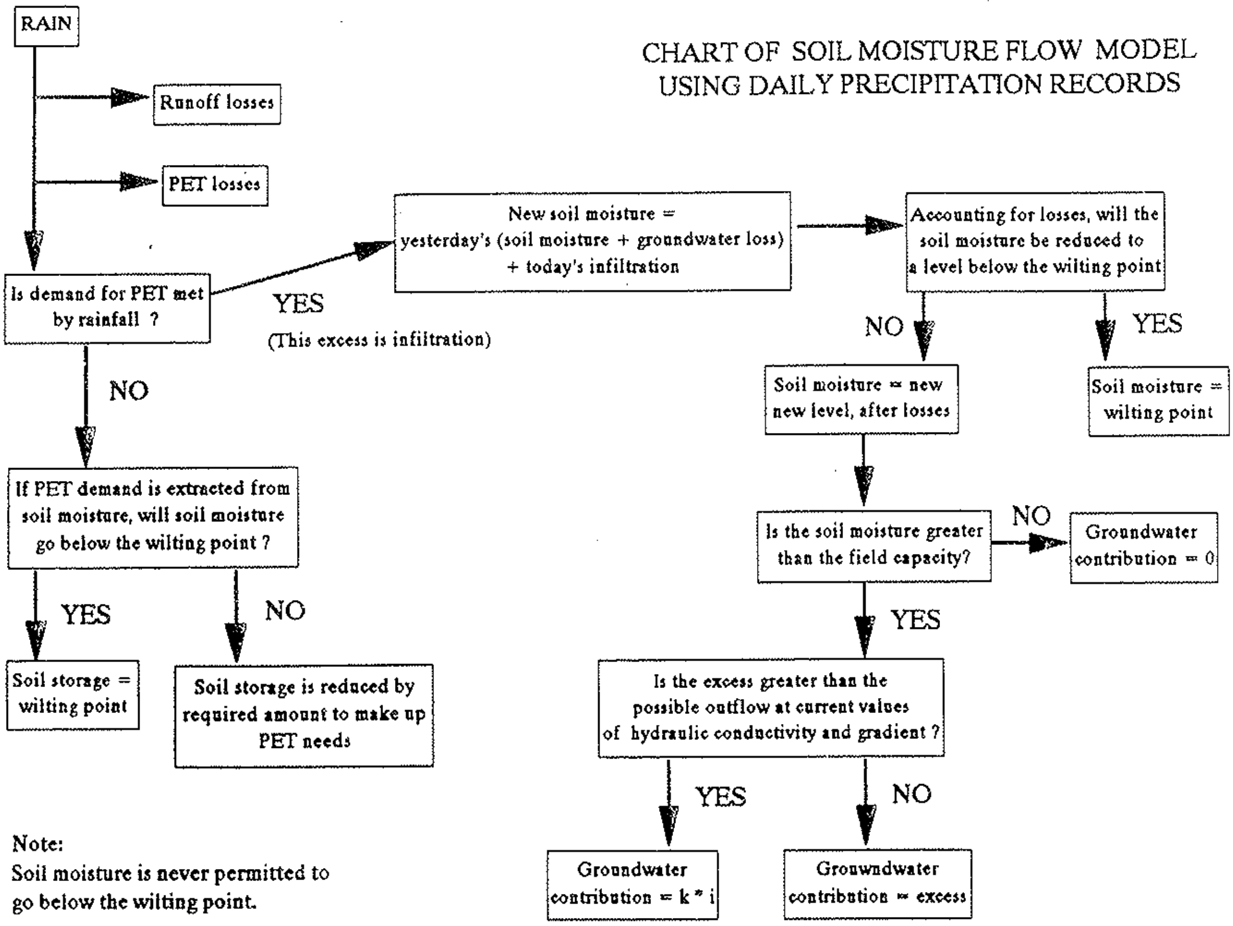


FIGURE G1

CHART OF SOIL MOISTURE FLOW MODEL
USING DAILY PRECIPITATION RECORDS



Note:
Soil moisture is never permitted to go below the wilting point.

FIGURE G2

Table G-1 - SUMMARY OF SELECTED DRY SEASON STREAM FLOWS AND RELATED CATCHMENT RAINFALL

SHEET NO	STREAM Number	STREAM NAME (see Note 4)	EASTING	NORTHING	ELEVATION (m-asl)	DATE	FLOW (L/s)	CATCHMENT AREA (km²)	FLOW PER PER AREA (L/s/km²)	MAJOR HYDROGEOLOGIC UNIT (note 3)	PRECIP. (see note 1) (mm)	RUNOFF (see note 2) (mm)	(%)
2	C_C261	MLUMATI (34)	297,600	1,650,100	335	82-85	1,210	740	1.6	GB + G3	1300	51.6	4.0
3	C_K381	KOMATI (30)	326,000	1,632,000	259	78-81	2,380	7,423	0.3	GB + G3 + G5	1000	10.1	1.0
7	C_U311	MBULUZI (3)	308,500	1,605,500	305	59-82	3,040	722	4.2	G5 + G3	1300	132.8	10.2
5	C_W161	MBULUZI (4)	270,700	1,600,100	975	Sep-69	400	168	2.4	G5 + G3 + GB	1100	78.0	6.3
9	C_K381	MBULUZI (32)	354,000	1,605,000	122	80-85	3,050	3,000	1.0	G5 + G3 + GW	1100	32.1	2.9
12	C_E231	MLUMATI (11)	289,000	1,646,500	427	55-82	2,010	585	3.4	GB	1300	108.4	8.3
13	CAE291	MBULUZANE (10)	303,000	1,582,500	381	54-82	310	223	1.4	GW	900	43.8	4.9
16	CAL001	LUSUTFU (31)	230,000	1,565,000	1,356	79-85	130	842	0.2	G3	1000	4.9	0.5
16	CAS021	BUZINGELI	235,230	1,542,850	1,067	01-Jun-90	47	14.8	3.2	GN	1150	100.5	8.7
16	CAT031	MPONONO	239,600	1,544,500	957	31-Jul-90	120	210	0.6	GN	900	18.0	2.0
16	CAT041	MTAGANE	241,400	1,543,430	957	04-Aug-90	60	11.3	5.3	GN	900	168.2	18.7
16	CAT051	UNNAMED	243,300	1,544,400	949	04-Aug-90	2	1.0	1.9	GN	900	60.6	6.7
16	CAT052	UNNAMED	244,300	1,543,520	961	04-Aug-90	0.2	0.58	0.3	GN	900	11.0	1.2
16	CAT061	UNNAMED	246,000	1,543,250	939	04-Aug-90	1.5	1.3	1.1	GN	900	35.3	3.9
16	CAT062	UNNAMED	246,150	1,543,400	942	04-Aug-90	0.5	0.35	1.4	GN	900	45.1	5.0
16	CAT063	UNNAMED	247,100	1,543,600	963	04-Aug-90	4	0.45	8.9	GN	900	280.3	31.1
16	CAT071	UNNAMED	247,620	1,543,730	960	04-Aug-90	3	0.98	3.1	GN	900	97.0	10.8
16	CAT072	UNNAMED	248,120	1,543,500	933	04-Aug-90	1.2	0.70	1.7	GN	900	54.1	6.0
16	CAT073	UNNAMED	248,750	1,544,170	978	04-Aug-90	0.2	2.6	0.1	GN	900	2.4	0.3
16	CAU021	UNNAMED	236,580	1,541,570	1,003	04-Aug-90	4	2.5	1.6	GN	850	50.5	5.9
16	CAU031	UNNAMED	237,850	1,542,120	975	04-Aug-90	0.5	1.2	0.4	GN	850	13.1	1.5
17	CAL111	BUHLUNGU	257,750	1,562,680	835	Jul-90	260	42.0	6.2	GW + UC	1200	195.2	16.3
17	CAM111	UNNAMED	255,250	1,560,300	841	Jul-90	5	3.8	1.3	G3 + GW	1000	42.0	4.2
17	CAM112	LUSUTFU (9)	258,250	1,560,900	823	53-85	3,800	2,681	1.4	G3	1100	44.7	4.1
17	CAN111	UNNAMED	258,650	1,559,820	830	Jul-90	2	3.0	0.7	GW	1000	21.0	2.1
17	CAN112	DUDUSI	259,350	1,559,590	815	Jul-90	270	65.5	4.1	GW	1000	130.0	13.0
17	CAN151	UNNAMED	269,925	1,558,200	648	Jul-90	6	0.60	10.0	GD -	900	315.4	35.0
17	CAN161	SKALANDEFU	270,300	1,558,000	648	Jul-90	40	4.40	9.1	G5 + GD	1000	286.7	28.7

NOTES:

1) Average annual rainfall: based on a regional isoheyete (see Fig. 6)
2) Percent annualised runoff: based on actual flows at the end of dry season (Aug. to Sept) and average annual rainfall.
3) See descriptions on Table II
4) Number in brackets indicates Water Survey Gauging Station number (see locations on Fig. 20)

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Table G-1 - SUMMARY OF SELECTED DRY SEASON STREAM FLOWS AND RELATED CATCHMENT RAINFALL

SHEET NO	STREAM Number	STREAM NAME (see Note 4)	EASTING	NORTHING	ELEVATION (m-asl)	DATE	FLOW (L/s)	CATCHMENT AREA (km²)	FLOW PER PER AREA (L/s/km²)	MAJOR HYDROGEOLOGIC UNIT (note 3)	PRECIP. (see note 1) (mm)	RUNOFF (see note 2) (mm)	(%)
17	CAN182	JOLOBELA	272,000	1,558,150	637	Jul-90	60	17.5	3.4	G5 + GD	1000	108.1	10.8
17	CAO091	UNNAMED	254,400	1,557,200	954	Jul-90	12	2.0	6.2	G3 + GW	1000	194.1	19.4
17	CAO092	UNNAMED	254,850	1,556,830	938	Jul-90	105	12.3	8.6	GW	1100	270.3	24.6
17	CAO181	COLO	275,300	1,556,850	663	Jul-90	70	5.8	12.1	G5/UC + GD	1000	380.6	38.1
17	CAQ131	UNNAMED	264,500	1,552,475	1,052	Jul-90	4	1.4	2.9	G5	950	90.1	9.5
17	CAR101	UNNAMED	255,250	1,548,550	937	Jul-90	10	2.7	3.7	G5 + GW	1000	116.8	11.7
17	CAR102	UNNAMED	256,850	1,548,150	983	Jul-90	8	3.0	2.7	G5 + GW	950	84.1	8.9
17	CAR132	MTIMANE	263,250	1,549,550	884	01-Jun-90	121	19.5	6.2	GW	1000	195.7	19.6
17	CAR131	MTIMANE	264,150	1,548,350	835	Jul-90	64	32.0	2.0	GW	1000	63.1	6.3
17	CAR130	UNNAMED	261,800	1,545,600	869	01-Jun-90	8	2.5	3.2	GW	950	100.9	10.6
17	CAS132	UNNAMED	261,800	1,545,600	869	Jul-90	11	2.2	5.1	GW	950	161.3	17.0
17	CAS111	UNNAMED	259,450	1,546,550	896	Jul-90	20	4.4	4.5	GW	950	142.4	15.0
17	CAS131	UNNAMED	264,000	1,547,150	832	Jul-90	3	0.9	3.3	GN	950	105.1	11.1
19	CAN321	MZIMNENE	311,500	1,559,700	320	15-Sep-86	1.8	35	0.05	G5	790	1.6	0.2
19	CAO331	MZIMNENE	312,500	1,556,300	274	19-Jul-86	2.2	120	0.02	G5	700	0.6	0.1
19	CAR351	LUSUTFU (6)	318,400	1,548,400	183	Sep-62	18,430	12,559	1.47	G3 + GW	1000	46.3	4.6
21	CAK481	PALATA	351,600	1,566,100	549	Nov-90	3	6.35	0.47	LR	846	14.9	1.8
22	CAU001	NGWEMPISI (21)	231,100	1,541,000	1,036	74-84	690	1,526	0.45	GW	850	14.3	1.7
22	CAV011	UNNAMED	233,500	1,538,800	1,015	04-Aug-90	50	17.0	2.9	GD	800	92.8	11.6
22	CAV021	BOSCH HOEK	235,350	1,539,000	1,059	04-Aug-90	10	3.0	3.3	GD	850	105.1	12.4
22	CAV071	TSAWELA	249,600	1,539,700	968	31-Jul-90	160	62.4	2.6	GN	850	80.9	9.5
22	CAW001	HLELO (22)	231,500	1,537,000	1,036	74-85	550	816	0.7	GR	900	21.3	2.4
22	CAW051	UPPER TSAWELA	243,950	1,536,200	1,090	31-Jul-90	110	29.9	3.7	GN	800	116.0	14.5
25	CAY311	MHLATUZANE (12)	308,400	1,530,800	290	65-82	460	365	1.3	GN + GD	800	39.7	5.0
25	CBC341	MHLATUZE (13)	317,000	1,523,000	274	67-82	340	215	1.6	GN + MZ	850	49.9	5.9
30	CBN341	UNNAMED	316,400	1,493,350	323	20-Sep-90	3.0	19	0.2	GN	800	5.0	0.6
30	CBO371	MATSANJENI	323,300	1,487,050	259	20-Sep-90	1.0	24	0.04	KE	730	1.3	0.2
31	CBJ441	NGWAVUMA (8)	340,100	1,506,700	195	Sep-62	1204	1,305	0.9	GR	850	29.1	3.4

NOTES:

File Name: 82-462\swflow\streamsm — Printed on: 13-Jan-92 08:03 PM

1) Average annual rainfall; based on a regional isoheyets (see Fig. 6)

2) Percent annualised runoff; based on actual flows at the end of dry season (Aug. to Sept.) and average annual rainfall.

3) See descriptions on Table II

4) Number in brackets indicates Water Survey Gauging Station number (see locations on Fig. 20)