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Department of Technical Co-operation for Development

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GROUND WATER IN EASTERN, CENTRAL AND SOUTHERN AFRICA

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NOTE

Symbols of United Nations documents are composed of capital letters combined with figures. Mention of such a symbol indicates a reference to a United Nations document.

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FOREWORD

The Economic and Social Council, by resolution 675 (XXV) of 2 May 1958, requested the Secretary-General to take appropriate measures for the establishment, within the Secretariat, of a centre to promote co-ordinated efforts for the development of water resources. It also singled out ground-water problems as one of the priority subjects in the development of a programme of studies. Large-scale Ground-water Development, published in 1960 1/, was the first study prepared in this field by the Water Resources Development Centre (now the Water Resources Branch of the Division of Natural Resources and Energy, Department of Technical Co-operation for Development).

The Advisory Committee on the Application of Science and Technology to Development, in its World Plan of Action 2/, gave priority to ground-water exploration and development. In fact, in the course of the First and Second United Nations Development Decades, more than 100 projects assisted by the United Nations Development Programme (UNDP) and other United Nations technical co-operation programmes were entirely or partially devoted to ground-water prospecting, assessment or pilot development. (A list of ground-water projects in the Eastern Mediterranean and Western Asia sponsored by UNDP is contained in the annex to the present report.)

While such operational activities were developing, the need for a comprehensive review of the results of the projects and for a dissemination of relevant information became more evident. As a result, the Economic and Social Council, by resolution 1761 B (LIV) of 18 May 1973, requested the Secretary-General to take the necessary measures, within the budgetary limitations, to improve and strengthen the existing United Nations services for the analysis, evaluation and dissemination of world-wide date on natural resources, including water resources.

With respect to ground water, a first comprehensive review of the African continent was published in 1972 and 1973 under the title Ground Water in Africa 3/ as a synthesis of material available in the records and files of the United Nations. The material of the second volume in this series, Ground Water in the Western Hemisphere 4/, was drawn from country papers which were prepared by hydrogeologists and by ground-water engineers, specialists of the countries concerned. This was also done for the third volume entitled Ground Water in the Eastern Mediterranean and Western Asia 5/, for the fourth, entitled Ground Water in the Pacific Region 6/ for the fifth, entitled Ground Water in Continental Asia 7/, for the sixth, entitled Ground Water in North and West Africa 8/, and for the present volume, the seventh in the series, which is to be followed by an eighth on ground water in Europe. This

1/ United Nations publication, Sales No. E.60.II.B.3.

2/ United Nations publication, Sales No. E.71.II.A.180.

3/ United Nations publication, Sales No. E.71.II.A.16.

4/ United Nations publication, Sales No. E.76.II.A.5.

5/ United Nations publication, Sales No. E.82.II.A.8.

6/ United Nations publication, Sales No. E.83.II.A.12.

7/ United Nations publication, Sales No. E.86.II.A.2.

8/ United Nations publication, Sales No. E.87.II.A.8.

will complete the presentation of (a) a necessarily brief but full overview of the world's ground-water resources, (b) the state of knowledge about them and their potential, and (c) information about their exploitation and the problems involved.

The present work indicates the progress made since the publication of the first volume on ground water in Africa. A point to note is the large number of African specialists who have taken part in the drafting of the text. There is now hardly a single African country which does not have university graduates or engineers specializing in hydrogeology or ground water.

It is to be hoped that this volume, which deals with several arid countries, in particular the countries of Eastern and Southern Africa affected by long periods of severe drought since 1983, will contribute to the development of ground water which is so vital in this part of the world.

The United Nations wishes to thank for their valuable assistance the governmental organizations and the consultants and experts on Africa and other countries who have collaborated in the preparation of this work, in particular the Ministry of Mineral Resources and Water Affairs of the Republic of Botswana, the Department of Geology of the Republic of Burundi, the Ministry of Mines and Energy of the People's Republic of Congo, the Agricultural Engineering Service of the Republic of Djibouti, the Hydrogeology Department of the Ethiopian Institute of Geological Surveys, the Inter-African Committee for Hydraulic Studies at Ouagadougou, the Department of Land Valuation and Water of the Republic of Malawi, the Central Water Authority of Mauritius, the Public Utilities Corporation of the Republic of Seychelles, the National Water Well Association (USA), the Executive Secretariat of the National Action Committee for Water and Sanitation of the Republic of Zaire, the Ministry of Agriculture and Water Development of the Republic of Zambia, and the Office of Geological and Mining Research (BRGM-Orléans, France), as well as S. Bonfa, J.L.T. De Sommerville, D. Ferro, J.J. Imangue, S. Jacobi, J.H. Johnson, E.P. Kabunduh, F. Kolman, D. Labodo, C.L. Lekkerkerker, S. Makhoalibe, J.S. Makundi, J. Margat, A. Navarro, T. Nkanira, J. Nowacki, R. Pozzi, J.H. Rakotondrainibe, N.S. Robbins, G. Rogbeer, E.M. Siamachoka, L. Stieltjes, C. Uramutse and P. Wurzel.

The colour map of the ground-water resources of Africa, which will be found in the jacket, was kindly supplied by Mr. J. Margat, chief of the water mission of BRGM Orléans, France. He is warmly thanked for that. The Division of Natural Resources of the United Nations Economic Commission for Africa (ECA, Addis Ababa) helped with the collection of information on some countries for this publication, for which ECA is jointly responsible with the United Nations Secretariat in New York.

Explanatory notes

The following symbols have been used in the tables throughout the report:

A dash (-) indicates that data are not available or are not separately reported.

A blank indicates that the item is not applicable.

A full stop (.) is used to indicate decimals.

A slash (/) indicates a crop year or financial year, e.g. 1976/77.

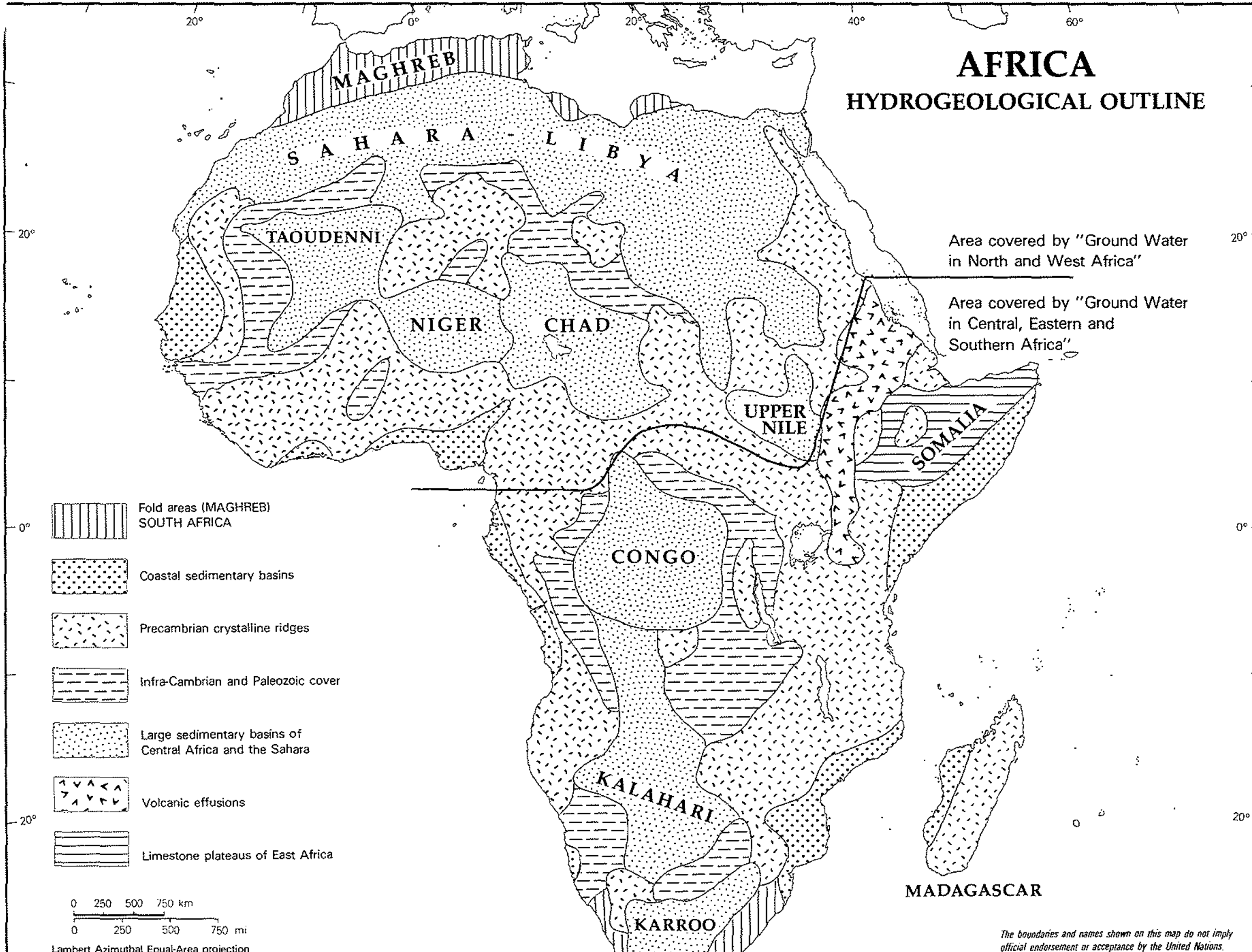
Use of a hyphen (-) between dates representing years, e.g. 1975-1978, signifies the full period involved, including the beginning and end years.

Reference to "dollars" ($) indicates United States dollar.

Details and percentages in tables do not necessarily add to totals because of rounding. Some of the data series are not homogeneous; they have been taken from various reviews and publications; the differences or divergences may be due to typing errors.

The designations employed and the presentation of the materials in this publication do not imply the expression of any opinion whatsoever on the part of the Secretariat of the United Nations concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries.

The term "country" as used in the text of this report also refers, as appropriate, to territories or areas.



AFRICA
HYDROGEOLOGICAL OUTLINE
MAGHREB
SAHARA - LIBYA
TAOUDENNI
NIGER
CHAD
UPPER NILE
SOMALIA
CONGO
KALAHARI
KARROO
MADAGASCAR
Area covered by "Ground Water in North and West Africa"
Area covered by "Ground Water in Central, Eastern and Southern Africa"
Fold areas (MAGHREB) SOUTH AFRICA
Coastal sedimentary basins
Precambrian crystalline ridges
Infra-Cambrian and Paleozoic cover
Large sedimentary basins of Central Africa and the Sahara
Volcanic effusions
Limestone plateaus of East Africa
0 250 500 750 km
0 250 500 750 mi
Lambert Azimuthal Equal-Area projection
20°
0°
20°
40°
60°
20°
0°
20°
The boundaries and names shown on this map do not imply official endorsement or acceptance by the United Nations.

PART ONE - OVERVIEW

This volume deals with ground water in Eastern, Central and Southern Africa from the standpoint of the deposits of this natural resource, the state of knowledge about its potential, its exploitation and the uses to which it is put. It deals with all the African countries located entirely or partly in the southern hemisphere, with the addition of the Republic of Djibouti and Equatorial Guinea. The other African countries, i.e. those situated in North and West Africa are dealt with in a sister publication.

I. LARGE AQUIFER SYSTEMS

This vast territory of more than 13 million km^2 with 230 million inhabitants can be subdivided on the basis of geological, morphological and climatic considerations into a number of large aquifer systems in which the ground-water resources can be reasonably well distinguished from the standpoint of their accumulation, their fossil or renewable state and their accessibility.

(i) The Precambrian crystalline basement rock which forms the continental mass outcrops - or suboutcrops - in a band 100 to 300 km wide, inland from the Atlantic coast in Equatorial Guinea, Gabon, Congo, Zaire, Angola, Namibia and South Africa. The outcrops are much larger towards the east, for the crystalline formations are in places raised above the big Rift Valleys - major tectonic depressions, the floors of which are covered by a series of big lakes. Masses of outcropping or suboutcropping crystalline formations are found in almost all the countries considered here. In some countries such as Rwanda, Burundi, Tanzania, Kenya, Zimbabwe and Madagascar, they cover most of the land area.

(ii) The sedimentary formations which overlie the depressed crystalline basement in the axial part of the continent. This includes the basins of the Zaire, the Okavango, and the Kalahari. The Karroo basin is a fossil basin raised in a vast plateau. Mention must be made, at the edge of the basement rock, of the "stromatolithic" calcarodolomitic Lower Cambrian formations which are very extensive in Congo, Gabon, Zaire and in Angola, Namibia, Tanzania and Zambia.

The essentially Continental formations of the Karroo (Carboniferous and Triassic) consist of fairly coarse sandstones which are good aquifers. The sand and sandstone formations of the Kalahari (Neogene-Pleistocene), likewise continental, can also provide good aquifers.

(iii) The vast basalt effusions resulting from the tectonic movements which have affected the African continent at various periods since the end of the Triassic, especially in Ethiopia and in the Rift Valley zone, Kenya, Tanzania and Rwanda, and in South Africa, Botswana and Madagascar. These volcanic formations provide springs in accidented areas (Ethiopia). When they form vast tablelands, as in Kenya, they provide large aquifers exploited by borehole but the water layer can be fairly shallow.

(iv) The sedimentary coastal basins, which differ very greatly in size: the Gabon basin, the narrow basin which covers the whole of the west coast from Angola to the Cape, the vast basin of variable width of Somalia-Kenya Tanzania-Mozambique, and the basin of the west coast of Madagascar. These basins consist of Recent, Quaternary and Cenozoic sediments, in which the sandstone-sand and limestone strata form large aquifers, artesian in some cases.

II. CLIMATIC CONDITIONS: EFFECTS ON THE RECHARGE OF THE AQUIFERS

This vast territory is subject to very varied climatic conditions in which latitude plays an essential role. From the anticyclones of the South Atlantic and the southern Indian Ocean, which are high-pressure centres, the trade winds blow towards the Equator and are deflected westwards by the rotation of the earth. As a general rule, the winds blow from the oceans to the land, bringing rain as the high ground checks the wet winds. Some depressed areas such as the Rift Valleys receive little rainfall. Eastern, Central and Southern Africa has maximum average temperatures of over 20 °C, with 30 °C in the Ogaden and 35 °C in the Kalahari, and average minimum temperatures generally below 20 °C; these minimum temperatures decline from the equatorial zone to the Cape. The world's highest average temperatures have been recorded in southern Somalia.

The temperature ranges are very small in the equatorial regions (1 °C) but increase in step with distance from the equator: they reach 02 °C to 30 °C in the Kalahari.

The Sahara

The precipitation is irregular in the Sahara, with large seasonal variations from year to year.

The extreme south of the continent, the Cape region, has a rainfall pattern of the Mediterranean type (winter rains).

The very wet equatorial regions have two rainy seasons at the solar zenith - i.e. when the sun is high above the horizon - usually from March to June and from September to November. From 10 to 15 degrees of latitude the tropical regions have only one rainy season - from May to October. Lastly, the subtropical desert zone, in particular the Kalahari-Namib and Somalia, receives only occasional and irregular showers.

The annual rainfall is 2 to 6 m in Gabon, in the loop of the River Zaire, to the west of the Great Lakes, and on the east coast of Madagascar; it is 1 to 2 m on the Ethiopian plateau, to the north of a line between Mossamedes and Dar Es Salaam, on the east coast of Southern Africa, and over most of Madagascar; it is 500 to 1,000 mm to the south of the Mossamedes-Dar Es Salaam line, with less than 500 mm in Somalia, in some parts of Uganda, Kenya and Tanzania, and in the Kalahari and the south-west part of Madagascar.

Climatic zones

The climatic zones, characterized by very different vegetation types, are as follows:

- Mediterranean zone with dry summers (hot season): Cape region.

- Steppe zone with a semi-arid tropical climate, i.e. with rainy summers (cool season). The precipitation is less abundant and the temperature ranges are larger than in the Mediterranean zone: this includes the whole of Eastern Africa with the exception of the coastal areas and the highest plateaus, and the central part of South Africa. The dry savannah zone (tall grasses) forms the transition between the steppe - with short grasses - and the wet savannah.

- Wet savannah zone or zone of wet tropical climate. Here the wet season grows longer the closer to the equator, but in some places the uninterrupted dry season can last from four to five months. The belt of wet savannah is 500 km wide on average.

- Desert zone (Kalahari-Namib and Somalia).

- Equatorial forest zone with very wet climate and two rainy seasons, or continual rain: it includes the Congo basin as far as the Rift Valleys.

- Coastal fringe zone, a narrow coastal strip in which the climate is heavily influenced by the sometimes very powerful coastal currents.

The current of Benguela flowing south-north from Cap to the equator, is a cold current. The warm currents are those flowing north to south from the Mozambique channel towards the Cape, and the monsoon current flowing south to north from Mozambique to Somalia, with surges of cold water in the area of Cape Ghardafui.

Aridity and evaporation

The climatic zones can also be classified according to the index of humidity or aridity (Thornthwaite), which takes into account both the temperature and the rainfall and its distribution and which expresses a characteristic ratio between potential evapotranspiration and the amount of rainfall.

Some evapotranspiration values are given below and compared with the rainfall values at a number of African weather stations:

Weather station	Annual precipitation (cm)	Potential evapotranspiration (cm)	Quotient %
Arid coastal regions			
Walvis Bay (Namibia)	1	78	17
Area of rainfall between 250 and 1,000 mm			
Lug Ferrandi (Somalia)	36	206	17
Garissa (Kenya)	31	187	17
Luanda (Angola)	33	134	25
Dodoma (Tanzania)	59	111	50
Catuane (Mozambique)	67	130	50

Thus, in some regions a large or very large proportion of the rainfall is lost almost immediately through evaporation. The heading "evapotranspiration" often has the highest values in the water tables. Some authors put forward the following figures for the various regions of Africa: evapotranspiration - 40 to 98 %; infiltration - 2 to 40 %; runoff - 2 to 12 %.

The surface water (lakes) is subject to wide variations in level owing to the imbalance in some years between the headings "evaporation" and "recharge". This is particularly true of Lake Victoria. It is also true of unconfined ground water when the water table is close to the surface (delta of the Okavango in Botswana). Evaporation determines - and can be measured by - the concentration of salts in the ground water. The question of the depth to which evaporation takes place is disputed. All authors agree that this effect operates for several metres (5 m on average and as deep as 8 to 10 m). Some authors speak of much greater depths.

Conclusion

The amount of rainfall available to recharge the ground-water aquifers depends on three main climatic factors: the annual rainfall, its distribution in time or the "heaviness of the precipitation", and the value of the potential evapotranspiration, which is essentially a function of latitude, altitude and temperature.

In some cases each of these three factors singly can have a decisive influence.

In all the regions in which the rainfall exceeds roughly 1 to 1.2 metres a year, neither the heaviness of the rain nor the evapotranspiration value should be taken into account, for a large part of the rainfall is almost always available for infiltration, in some places after runoff. In this case the decisive factor is the amount of the rainfall.

In the case of rainfall below 250 mm, it is the heaviness of the precipitation which is important. It is interesting to note that in conditions of increasing aridity - decline in rainfall accompanied by an increase in the evaporation potential - the heaviness of the showers increases to the point where most of the annual precipitation sometimes falls in a few hours. Accordingly, some daily figures can produce a surplus - which can persist over several days - of rainfall over potential evapotranspiration; this gives the water time to infiltrate and thus recharge local aquifers in particular cases.

In regions with rainfall between 250 mm and 1 m (steppe and dry savannah) the potential evapotranspiration is the decisive factor, for the rainfall is spread out better in time. During the rainy season, which can vary widely from one year to the next, the potential evapotranspiration can still have a large value. However, a very variable remainder is almost always available for runoff and infiltration. In contrast, during the dry season which can last from three to six months, some regions of Africa have climatic conditions of the semi-arid or arid type while receiving more annual rainfall than some countries in the wet temperature zone of Europe. During the dry season, the evaporation effect can be considerable in surface and shallow aquifers.

Some recent studies on the treatment of rainfall date in the savannah countries tend to show that the rainfall falls into two distinct categories:

- A "monsoon" system with moderate rainfall fairly well distributed in time and little variation from year to year. To some extent this rainfall can help to maintain the vegetation but most of the water evaporates after having soaked the supper layers of the soil.

- A system of very heavy, brief and frequent shows which produces large amounts of surface runoff and deep infiltration. This type of rainfall is essential for the renewal of surface and ground-water resources. It is the decline in the heaviness or frequency of these showers which causes "drought" and one of its main consequences: a drop in the level of water in the wells, which can even dry up completely. Lastly, a drop of 50 % in the amount of total annual rainfall as a result of less frequent showers can mean no surface runoff or recharging of the aquifers.

III. PRODUCTIVITY OF THE AQUIFERS

The values given below are by way of example. Additional data will be found in the country papers.

Coefficients: S = storage
K = permeability
T = transmissivity

1. "Porous" aquifers

Alluvial fill, deltas, Quaternary formations of the Congo basin, sedimentary coastal basins

Country	Location	Geology	Flow rate per installation (m^3/h) a/	Drawdown (m)	S %	K (m/d)	T (m^2/d)
			Fluvial alluviums				
These aquifers are among the most important and serve large populations.							
Congo (both Republics)	Congo (river)	Sands-gravels	(1 to 100 100 $m^3/h/m$)	-	-	-	-
Madagascar	Tananarive	Alluviums with clays	(15 to 40)	-	-	-	-
Zimbabwe	Sabi (river)	Non-argillaceous alluviums	60	-	-	-	-

a/ In the column "Flow rate per installation", the values in brackets indicate a specific discharge.

Country	Location	Geology	Flow rate per installation (m^3/h) a/	Drawdown (m)	S %	K (m/d)	T (m^2/d)
			Extensive alluvial fill				
Burundi	Graben	Fill formation	10 to 60	-	-	-	-
Congo	Basin apart from river	Fill formation	(1 $m^3/h/m$)	-	-	-	-
			Coastal sedimentary basins				
Madagascar	-	Cretaceous sandstones	60	-	-	-	-
			Kalahari sands				
Angola	-	Argillaceous-calcareous sandstones	2.5 to 4.5	-	-	-	-
Malawi	-	Non-argillaceous sands	1 to 5	-	-	-	-
	-	Argillaceous sands	0.5 to 3	-	-	-	-
Zimbabwe	-	Sands	Up to 70	-	-	-	-
Zambia	Barotseland	-	4 to 8 maximum	-	-	-	-
			Karroo sandstones and other Precretaceous or Cretaceous continental sandstones				
Madagascar		Isalo argillaceous sandstones	15 to 40	-	-	-	-
Namibia	Botswana frontier	Ecca sandstones (Karroo)	(40 to 4,000 per day, artesian)	-	8 to 15	-	-
Zimbabwe	-	Upper Karroo sandstone	3 to 6 (up to 50)	-	-	-	-
Swaziland	-	-	-	-	-	-	-

Country	Location	Geology	Flow rate per installation (m^3/h) a/	Drawdown (m)	S %	K (m/d)	T (m^2/d)
Zambia	-	Lower Karroo sandstone	Low	-	-	-	-
		Sandstone of Grit escarpment	7 to 10 (up to 60)	-	-	-	-
		Beaufort formations	20	-	3 to 10	-	-
Zimbabwe	-	Cretaceous conglomerates	2 to 7	-	-	-	-

2. Fractured aquifers

Karstified limestone strata

Country	Location	Geology	Flow rate per installation (m^3/h) a/	Drawdown (m)	S %	K (m/d)	T (m^2/d)
Madagascar	West coast	Eocene limestones	40 to 300, artesian (160 to 200 $m^3/h/m$ pumped)	-	-	-	-

Dolomitic-limestone massifs and plateaus of the Upper Precambrian and Cambrian

The dolomitic-limestone sedimentary system (Upper Precambrian and Cambrian) is often very thick and constitutes one of the most important ground-water reservoirs in Africa. This is borne out by the few examples given below:

Dolomites of the middle Katanga (Zambia): 4 to 10 m^3/h (40 m^3/h in the Mazabuka fault). The town of Lusaka draws 2,000 m^3/d from 10-inch boreholes;

Dolomites of Lubumbashi (People's Republic of Congo): specific yield - up to 100 $m^3/h/m$;

Dolomitic limestones of the Transvaal - Far West Rand (South Africa). Useful porosity: in the order of 10 % at 60 m, 2 to 3 % at 100 m, and 1 to 2 % at 150 m. The Suurbekom pumping stations supply 30,000 m^3/d to Johannesburg. A yield 30 times greater is available. The main purpose of the pumping in this region is to exhaust the limestone stratum which overlies the gold-bearing conglomerates, with a view to their exploitation. Over 15 years, 10^9 m^3 have been pumped.

3. Compact-rock aquifers

Formations with little or no porosity, except locally in suitable altered or fissured zones

Precambrian and Primary hard sandstones, schist-sandstones and quartzites

Example: Angola (southern)

Lower-Cambrian quartzites and conglomerates: Yield, 0.5 to 3 m^3/h.

Schists (mainly Lower-Cambrian, Paleozoic and Karroo) and clays

When they are not totally impermeable, these formations contain very few water resources, mainly in the fracture zones.

Example: Zambia - phyllades, biotitic schists, Katanga schists, yield per well from 1 to (exceptionally) 4 m^3/h.

Examples of available yields per well and borehole in crystalline formations

Country	Location	Geology	Flow rate per installation (m^3/h)
Angola	South	Metamorphic rocks	0.6 (fractured)
	Catuiti	Tectonized and alterated granites	3 to 30 (up to 80)
Congo	-	Granitogneiss in alterations and fractures	(1 to 10 m^3/h/m)
Madagascar	Various	Altered gneiss	0.4 to 1.2
Malawi	Various	Gneiss with graphited biotite	2 to 5
Mozambique	Various	Rhyolites	Springs: 0.1 to 0.5 (wells 1 m^3/d)
	Various	Granites paragneiss orthogneiss	4 to 8
	Porto Amelia, Villa Perry	Granites paragneiss orthogneiss	12 to 20 (up to 25)
Namibia	Namaqualand	Gneiss and quartzites	1 to 20 (artesian)
Uganda	Karamoja	Acid gneiss	5 to 50
Zambia	Kaloma Choma	Quartz veins	8 to 12

In fact, a flow rate of 5 m^3/h is a good yield for the granites and granitogneiss; a flow of 1 m^3/h is considerable for the micaschists and metamorphic schists. Better yields are obtained in the quartz zones.

4. Volcanic rocks

The lavas, especially the basalts, the dolerites and certain basic rocks which sometimes afford large yields can be classified in a separate category; some examples are given below:

Jurassic basalts (Zimbabwe) - artesian waters: 8 m^3/h;

Bulawayo lavas, tufas, etc. (Zimbabwe) metamorphized into green rocks: 8 to 15 m^3/h (exceptionally 70); certain lavas have a low yield of under 1 m^3/h;

Basalts (Mozambique): 3 to 4 and up to 25 m^3/h, with drawdown of 5 m;

Stormberg basalts (Swaziland): 1 to 2.5 m^3/h;

Karroo doleritic dykes (Swaziland): 1 to 4 m^3/h;

Akjoujt basic rocks (Mauritania): 30 to 45 m^3/h, with drawdown of 13 m;

Altered basic rocks (southern Angola): 7 to 12 m^3/h.

The volcanic rocks, and especially the basalts, also give large yields, in particular from big springs, in other countries (Ethiopia).

Conclusion

There is almost nowhere in Africa where ground water is not found at one depth or another. The biggest yields are provided by clay-free alluviums, continental or marine Cretaceous sandstones and karstic limestones.

Most of the ground water is acceptable for human consumption and therefore for livestock as well. In very general terms it can be said that, with respect to its quality, which depends on the geology, climate and geographical situation:

- In arid zones the ground water is usually of calcium/magnesium bicarbonate facies at the upstream level, i.e. near the regions where the surface runoff infiltrates. It then acquires a higher sulphate content and finally increased amounts of chlorine and sodium at the end of the course in the regions where the evaporation effect is high and operates directly on shallow aquifers;

- Some geological formations, especially of Permian-Triassic or Cretaceous age and lagoonal origin, contain mineral salts which pass in solution into the ground water. This is particularly the case in Mozambique;

- In the coastal sedimentary basins, often made up of permeable formations, pumping causes sea-water intrusion which tends to contaminate the fresh-water aquifers;

- In the Precambrian basement rock in tropical rain country the water is usually not very mineralized or aggressive.

Mineral-water and thermomineral springs abound in the African continent in the fractured zones. There is a large potential for geothermal energy in the Rift Valleys which is currently being exploited, especially in Kenya.

IV. EXPLOITATION OF THE GROUND WATER

Up to recent times in this part of the world, ground water was drawn off from crude wells - shallow holes dug in the alluvial beds of water courses devoid of surface water in the dry season. These wells are in general use in arid regions such as northern Uganda.

They are rarely more than a metre deep and provide temporary water points still frequented by nomads; they usually last only a short time, for flood water in any amount destroys them.

Wells drilled and dug by modern methods

In the deserts, the discovery of ground water by deep drilling is essential for oil exploration works, especially for the mixing of drilling mud and the raising of oil by injecting water under pressure. The general geological studies and the geophysical studies carried out for this purpose have led to the identification of deep confined aquifers which have then been exploited by means of artesian boreholes. Thus, even before the proclamation of their independence the African territories under British administration benefitted from the experience acquired in oil exploration in the Middle East during the second quarter of the 20th century and from the progress made in the same period by British and Swedish manufacturers of drilling equipment for the exploitation of ground water.

Ground water was first exploited by borehole in the arid zones of Southern Africa.

Many small boreholes have also been drilled in all the countries of the semi-arid or arid zone in order to supply from shallow aquifers the administrative or economic urban and rural centres and modern agricultural enterprises. These works were then extended to the wetter areas and as far as the equator, for the wet tropical countries also need ground water to supply their towns and villages.

The number of water-drilling rigs in Africa has increased rapidly over the past decade, especially in the arid countries. These rigs are used by a number of African and foreign companies and by State services such as departments of water development, or equipment, etc.

The boreholes are not usually equipped with motorized pumps. In rural areas many types of hand-operated or animal-traction pumps have been tried out. Some of these pumps are particularly simple and tough, for example the India Mark II developed with the help of UNICEF, and the Volanta of Netherlands'conception, which is now manufactured in Africa.

In addition to drilled wells, there are many wells dug by hand on the initiative of the administration in areas where they could not be constructed by the methods traditionally used by the local people (shovels and picks). In areas of hard rock, particularly Paleozoic schists and sandstones, compressed air tools and explosives are used to excavate the wells. These methods are usually costly and are going out of use.

In many African countries in the wet tropical zone the formations usually contain very loose clay seams which make it impossible to dig wells by hand, for the walls collapse even before the digger reaches the water-bearing strata underlying the clays. In such cases an appropriate lining must be used; this is always tricky and sometimes expensive or difficult, which means that the wells must be drilled.

The construction of wells is also very difficult in areas of sand-clay sediments where the installation of a prefabricated reinforced-concrete lining is always essential.

The installation of motorized pumps is justified only when the water requirement is large, and account must be taken of economic and social factors, the chemical quality of the water and the height of the lift. The communities or services concerned must also have the technical and financial means to maintain and repair the installations.

During the last 15 years the digging and drilling of wells has undergone spectacular development, partly as a result of the International Drinking Water Supply and Sanitation Decade and partly because of the periods of exceptional drought (1973-1975 and 1983-1985) which affected the arid subtropical zones.

Ground water is extensively used to supply urban and industrial areas, especially in arid regions and coastal zones. This is particularly true of Djibouti, Berbera, Mogadishu, Mombasa, Zanzibar, Gaberones, Pretoria, Windhoek, Lusaka and several towns in Zaire.

The exploitation of ground water in Africa is intended mainly to meet the water needs of the towns, villages and pastoral areas and also those of industrial and mining enterprises. In contrast, irrigation with ground water is limited either by its cost and the expenditure of convertible currency involved in the purchase of pumps, motors and fuel, or by the exhaustion of the aquifers in arid regions. Apart from the zones of semi-arid and Mediterranean climate in Southern Africa, the areas irrigated by ground water are still very small. However, the creation of small market-garden centres is envisaged in the vicinity of the motorized or hand pumps installed in the villages, with a view to diversifying the people's diet.

V. CONCLUSION

The sharp increase in the use of ground water in Africa goes hand in hand with the continent's rapid entry into the modern world. This use is important for all sectors of the economy but was first concentrated in the towns, the mining centres and some priority farming regions. It is now being extended to the small centres in the most isolated tropical and desert regions. A considerable effort to this end is being made both by Governments and by international and bilateral technical co-operation bodies. This sharp increase in the use of ground water is almost one of the fundamental conditions for economic and social development, for it is an essential factor in the life or survival of many existing centres of population and the fundamental condition for the establishment of new centres.

However, the development of ground water is beset with many difficulties. Firstly, the areas with the best aquifers from the standpoint of the capacity of the rocks to absorb, hold and discharge large quantities of water are often arid or even desert zones with little or no recharge from rainfall and coastal zones subject to deep intrusion of sea water in the direction of the wells. In contrast, some rainy tropical zones have rocks which are poorly suited to the absorption and storage of water supplied by rainfall and surface runoff.

Furthermore, ground-water prospecting and the drilling and digging of wells are usually difficult and expensive operations owing to the weakness of the infrastructures, the unfavourable natural conditions, the remoteness of the zones to be reached and the wide dispersal of the villages, as well as the lack of equipment, qualified personnel, project-uptake facilities, and investment and maintenance funds.

Lastly, and this is not the least problem, African villagers and herdsmen do not everywhere have the motivation, the basic technical capacity and the material resources required for the satisfactory operation, maintenance and repair of the manual pumps supplied to them. Substantial progress has nevertheless been made in recent years in several fields: training of technical personnel at various levels, including management and decision-making; rational planning of drilling operations; introduction of relatively cheap and effective methods of prospecting (particularly remote-sensing and geophysical techniques); computerization of data and inventories; manufacture of equipment - especially hand pumps - in Africa itself (Tanzania); grassroots animation and education of villagers and creation of African water-drilling enterprises.

However, much remains to be done to ensure that the ground-water resources of arid Africa are managed to best effect, i.e. without wastage or medium and long-term threat to the quantity and quality of these resources. This comment applies equally to the intensively exploited coastal zone, especially at Mogadishu and in southern Madagascar.

Nor are the objectives of the International Drinking Water Supply and Sanitation Decade about to be achieved for the villages. However, it can be hoped that towards the end of the century the necessary infrastructures - wells and boreholes - and the corresponding elementary superstructures will be in place in all the villages and that the maintenance of the pumps, if not their replacement when they are worn out, will be undertaken mainly by the villagers themselves.

United Nations. 1989. Groundwater in Eastern, Central and Southern Africa: Swaziland. United Nations Department of Technical Cooperation for Development.

MAP 25. SWAZILAND — GENERAL MAP

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SWAZILAND

Area: 17,360 km^2
Population: 600,000

I. BACKGROUND

Swaziland is a landlocked country situated between the Republic of South Africa in the west and Mozambique in the east. It can be divided into four regions on the basis of physiographical criteria:

The Highveld (or "Inkangala") which covers about 29 % of the country. This is a mountainous area consisting mainly of large granitic masses, with very ancient metamorphic rocks in the north-west with a few high peaks such as Bulembu (1,862 m) and Ngwenya (1,828 m). The watercourses of this region have cut deep valleys in the massif.

The Middleveld ("Live") which is an intermediate area between the Highveld and the Lowveld. It occupied 26 % of the country and is the most densely populated area. This is gently undulating terrain resting on a granitogneiss rock mass, with open plains and low hills. The altitude is between 300 and 1,050 m. Tall grasses are the main natural vegetation. Agriculture is well developed here.

The Lowveld ("Lihlanze") is the largest area of the country (covering 37 %); it is of low altitude and consists of Karroo sedimentary rocks. The altitude varies from 150 to 300 m and there are some ranges of hills.

The vegetation is typical of the Bushvels with thornbushes and grasses. Sugar cane plantations are undergoing considerable development in areas where ground water can be used for irrigation. The Lubombo mountains cover 8 % of the country in a narrow strip along its eastern edge. These mountains are in fact a steep-sided plateau rising from the Lowveld and consist of volcanic rocks of the Upper Karroo. The altitude increases from the Lowveld up to 777 m and then gradually declines towards the east. The main watercourses have cut deep gorges in these mountains. There is a degree of oceanic influence on the vegetation.

Climate and rainfall

The country has a good network of meteorological stations. The Manzine and Stegi stations were established in the last century. About 60 pluviometric stations have been in operation for more than 20 years.

Maximum and minimum temperatures have been recorded at 25 stations for more than 20 years. Additional less abundant but adequate weather data are available.

Swaziland's climate is of the subtropical type. The capital, Mbabane, is situated 300 km south of the Tropic of Capricorn. The rainfall is strongly influenced by the relief; it increases by 25 mm a year for each additional 30 m of altitude.

The summer rains are brought by the prevailing winds. The Lowveld, to which rain is brought only by convection currents, receives 500-600 mm.

The Highveld, where the warm wet air is forced upwards by the topography and convection, receives 1,600 mm on average.

In the Middleveld and Highveld the rain falls in heavy showers which can sometimes be rendered torrential by Indian Ocean cyclones. The three cyclones this century occurred in 1925, 1966 and January 1984; the last one (Cyclone Domonia) was the most violent in living memory and caused considerable damage everywhere.

The average annual rainfall for the whole country is about 890 mm, 710 mm falling in summer and 180 mm in winter. This standard pattern can vary. For example, during the summer of 1977-1978 the average was 50 mm, as against 560 mm during the winter of 1943. The largest amount of rainfall recorded in a calendar year was 3,300 mm at Nottingham near Piggs Peak, and the smallest amount was 200 mm at Lavumisa in 1935. There seem to be alternating wet and dry periods.

Temperatures

Like the rainfall, the average air temperatures are influenced by the relief, with a maximum of 22 °C in the eastern Lowveld and a minimum of 16 °C in the Highveld; this represents a drop in temperature of half a degree for every 100 m of altitude. The highest recorded maximum was 49 °C in the east of the country, but only 36 °C at Bulemba at the western frontier. The lowest recorded minimum was -6 °C at Mbabane.

In winter the zone of the south-east prevailing winds shifts northwards and Swaziland comes under the influence of an east-west high-pressure front. This usually brings clear dry weather with wide daily temperature ranges, cool nights and hot days. In spring and autumn cold fronts preceding masses of polar air push the warm tropical air upwards and bring rain and cold.

Losses of water through evaporation from the soil, plants, watercourses and lakes are higher at low altitude where the sky is clearer. In winter, losses of water through evaporation are higher owing to the clearer skies and the presence of masses of dry continental air.

Surface water

While most of Southern Africa has climatic conditions of the arid or semi-arid type, Swaziland is benefited from the standpoint of resources by the large rivers which cross the country. A volume of 144 m^3/s, i.e. about 45 billion m^3 a year, leaves the country; this is a considerable amount for Africa.

The flows of the watercourses are diminished by drawoffs both in South Africa where some of these rivers rise and during their passage through Swaziland. At present Swaziland uses almost 50 m^3/s, i.e. about one-third of the volume of water which leaves the country.

Almost all the watercourses of the Highveld are perennial, owing to the fairly high rainfall and the presence of permeable strata which can absorb and then transmit the water to the watercourses. In contrast, the watercourses of the Lowveld, except for the big rivers, flow only after heavy local storms. Even in the permanent streams the flow varies considerably owing to the seasonal nature of the rainfall. The maximum flows occur a the end of summer, i.e. in January, February and March, with the minimums in July or August. The main rivers rise in the Highveld. They are the Mlumati, Komati, Mbuluzi, Lusushwena, Lusutfu, Ngwempisi, Mkhondvo and Ngwavuma, which flow eastwards towards the Indian Ocean.

Of these rivers the Lusutfu, which rises in the Transvaal, has the largest flow: it crosses the Lubombo mountains in a dramatic gorge before reaching the sea. Next in size is the Komati but its flow is less than half that of the Lusutfu. The Mbuluzi and the Ngwavuma rise in Swaziland, but the Ngwavuma dries up un very dry years.

The total flow of Swaziland's watercourses is equivalent to 150 mm of the rainfall, i.e. 17 % of the total rainfall of 882 m for the drainage basins in Swaziland and South Africa. In the Highveld the flow coefficient can be 10 times higher than in the Lowveld. For example, the Komati's flow upstream of the Vergelegen measuring station is 329 mm (20 % of the rainfall), while the Mbuluzi's flow in its lowest reaches (station 20) is about 25 mm (4 % of the rainfall).

According to a number of chemical analyses, the total mineral content (dry residue) of the river water is usually below 150 ppm and even below 30 ppm in the streams in the granitic formations of the Highveld.

II. GEOLOGY

Most of the country consists of Archean granites and gneiss of the western part of the Kaapvaal crater. These rocks, together with the ancien metamorphic rocks of the Swaziland and Angola supergroups, constitute the high plateaus in the west and centre of the country. Further east are found the Karroo volcanic and sedimentary rocks of Permian to Jurassic age which form the eastern side of the crater in the Lowveld and the Lubombo mountains.

Swaziland has sedimentary rocks which are among the oldest in the world - the Swaziland group. The oldest belong to the Onverwacht group and are 3,400 million years old. This group is overlain by the Fig-Tree and Moodies groups which contain argillaceous schists, cherts and quartzites. The Fig-Tree group also contains ferrous strata which have been worked at Ngwenya. All these rocks are very resistant to erosion, and this is the reason for the rugged relief in the north-east of the country.

The predominant rocks of the Middleveld are ancient granites and gneiss. These are Archean rocks more than 2,000 million years old. Owing to their varying chemical composition these rocks are differently marked by erosion; this factor produced the hills and valleys of the Middleveld. The Karroo rocks were formed from a long sequence of shallow terrestrial or marine sediments. At the base are found tillites more than 300 million years old and glacial sediments; at that period Southern Africa was centered over the South Pole. Overlying these rocks there are various argillaceous schists and sandstones with coal seams which are being worked at present. At the summit are found volcanic rocks: basalts and rhyolites which spread over the soil about 200 million years ago in the period immediately preceding the splitting of the southern supercontinent known as Gondwanaland. These Karroo rocks are traversed by many doleritic dykes and sills.

Swaziland has few unconsolidated or partially cemented sediments of Cenozoic to Recent age. They are found only in a few valleys and flood zones of the main rivers. In fact, most of the rivers flow directly over the rocks, which they have deeply incised in places.

III. GROUND WATER

The lack of drilling rigs prevented Swaziland's Geological Service from making accurate studies of the country's ground-water potential until very recently; but a short time ago the arrival of two rigs from Canada lead to the initiation of systematic studies, with test pumping basin by basin. At present reports are available on brief reconnaissance exercises, together with reports prepared by United Nations/United Kingdom consultants on short missions.

An inventory has been made of all the country's springs, the majority of which are found in the Highveld and the upper Middleveld. A total of 161 springs have been mapped, with yields from 01. to 6 l/s. A ground-water development section was set up in 1974 in the Geology and Mines Service with the main task of digging and drilling wells in the rural areas of the Lowveld. This section is also responsible for advising the Government and the public on the sitting of boreholes and their installation. The successes obtained in the installation of productive boreholes have gradually reduced the use of water-diviners in the government services.

The number of boreholes currently in use is estimated at 300 but the exact figure is not known, for drilling for water is not yet subject to declaration with details of dimensions and yield.

The hydrogeological studies are based mainly on examination of geological maps (1:50,000) and interpretation of aerial photographs. In many cases the ground water is contained in fracture and breccia zones which can be detected on aerial photographs.

Electrical geophysical prospecting (resistivity method) has been used with great success in ground-water exploration in Swaziland. The Geological Service is making studies at several sites. A Canadian prospecting team recently obtained promising results in the Lowveld using electromagnetic techniques which identified structures saturated with water. Doleritic dykes have also been located by magnetometric methods. However, many of the dykes are non-magnetic, especially if they are unaltered. Dykes are known to be a favourable indicator of the presence of ground water.

Ground water in the pre-Karroo formations

With the exception of the Insuzi and Mozaan series, these formations consist of massive crystalline rocks with very poor primary permeability. The most productive boreholes are those which penetrate the joints (secondary permeability) or are located adjacent to dykes or basic intrusions, although some boreholes find water in altered zones. Clays produced by intense alteration can impair the yields in certain areas. In many cases small perennial streams are found in the areas of contact with dolerites.

The data studied by Robins in 1978 indicated that 39 % of the holes bored in gneiss and 46 % of those in granites furnished less than 0.5 l/s, with an average yield of 1.1 l/s. However, yields are often obtained from boreholes drilled close to villages, health centres and schools which are in many cases situated near the summits of the mountain chains (Versey, 1977). This may be due to the fact that these chains were shaped by differential erosion and thus the degree of alteration and fracturation of the rock is less developed than in the valleys where the drilling sites are more promising.

Many boreholes in the Ezulwini valley and the Malkerns Farmlands draw their water from the permeable altered zone overlying the solid rock. The Ezulwini test hole identified a three-metre layer of red clays with poor permeability overlying 20 metres of permeable sands produced by the alteration of granites and gneiss. This alteration developed in situ, for traces of quartzitic veins are found in the clays. A similar red clay is present in the Malkerns valley at a depth of 30 m. One of the wells of the Swazi Spa Hotel has a yield of 6.9 l/s. The hydrogeological properties of the Insuzi and Mozaan series are unknown. However, it is probable that the lavas and argillaceous schists have poor primary permeability. The ground water can also be exploited when secondary permeability is present.

The holes bored in granites give slightly higher specific yields (0.046 l/s/m) than those in the Ancient gneiss complex (0.033 l/s/m) but this is to be expected in the light of the clearly higher yields obtained in the altered granite basins of the Malkerns and Ezulwini valleys.

Ground water in the Karroo rocks and Recent sediments

A uniform shallow aquifer is situated at the base of the Karroo system and in the altered upper part of the underlying Archean rocks. This aquifer gives generally poor yields. However, it is used to supply a coal mine and a refugee camp in the Mpaka area.

The Karroo sediments are well cemented, with porosity in the order of 0.5 to 2,5 %. It is not surprising that the granulometry of the deltaic sediments should be variable and in all cases below 0.5 mm. Secondary porosity is therefore essential if large yields are to be obtained. Joints are found only in the argillaceous schists and coal seams and they yield water of poor quality.

In the light of the exploratory diamond coring carried out by the Geological Service under the new coal project at Mpaka, it seems certain that below a depth of 80 m there is little permeability associated with fractures or alteration. There are few joints in the volcanic rock either. The open joints cease to yield water a few metres away from the deep dykes and faults. Only when they are altered and situated in low zones do they furnish water in any quantity. Some of the faults are blocked by red clays. The best conditions are found in the contact zones in the vicinity of doleritic dykes. In these zones 80 % of the boreholes are productive. The fractures are open to a depth of 20 m. Below that level they have been closed by compaction. It has been established that the best yields are obtained at less than a metre from the contact with the dyke and the compact rock. A dyke may contain some water in its alteration zone.

There are several types of basalt in the Lowveld:

- Amygdaloid basalts which are found only in the Lubuli area; they are easily altered and rarely outcrop. The amygdules include quartz, carbonates, zeolites, epidotes and chlorites;

- The porphyritic basalts have not been accurately delimited. Most of the altered basalts are good aquifers;

- The interstratified agglomerated basalts in the acid volcanic rocks are also good aquifers in the Lowveld. The productivity of the aquifers in the basaltic formations is determined by their physical properties such as porosity and permeability, the size and distribution of the vesicules, the number and spacing of the joints, and the extent of the alteration.

Of the 92 boreholes inventoried in the Karroo, 21 are barren and 56 yield under half a litre per second. Similar results have been obtained in South Africa. However, in the Lowveld of Swaziland the density of the dykes is higher in the south and the ground-water potential is therefore greater. In the Karroo system the boreholes in the Ecca sediments have slightly higher specific yields (0.028 l/s/m) than the boreholes in the lavas (0.023 l/s/m).

Little water is extracted from the alluviums, for they are generally thin and occur in narrow strips in the valleys. They play an important role only when constituting a natural filter for water pumped from the bed of the watercourse.

Water quality

In most cases Swaziland's ground water has low concentrations of dry residue and is neutral to slightly acid, with pH of 6 to 7. The lowest concentrations are due to leaching through the shallowest aquifers. For example, in the Highveld and Middleveld the steep slopes and heavy rainfall hold the dry residue below 500 mg/l. However, the ground water in the Lowveld and Lubombo mountains in eastern Swaziland is more saline, with a dry residue often in excess of 1,000 mg/l.

The granitogneiss regions of the Highveld and Middleveld furnish the country's best ground water. The four holes drilled in the metamorphic granites and schists of the Lowveld have a dry residue below 80 mg/l and usually closer to 30 mg/l. The surface water in the west of the country has a similar dry residue. In the Middleveld the metamorphic rocks and some of the Karroo sedimentary rocks have a slightly higher mineral content: 100-500 mg/l and up to 1,000 mg/l. The water is slightly acid (pH 6 to 7) owing to the presence of carbonic acid in the recharge zone and the lack of calcite sediments in the cations. The dominant element is sodium or calcium, sometimes with magnesium present in similar or higher concentrations. Bicarbonate is the commonest anion owing to the incorporation of atmospheric or organic CO_2. The concentration of CO_3H may also result from the dissolution of hydrothermal carbonated minerals in the metamorphic rocks. The chlorine content is usually 10 mg/l with up to 200 mg/l in exceptional cases. The sulphate content is usually below 5 mg/l. In the Lowveld and the Lubombo mountains the ground water of the Karroo sediments and the volcanic rocks has undergone more intensive interaction with the water-bearing rocks and therefore has a higher mineral content. Samples taken from the boreholes indicate concentrations often in excess of 1,000 mg/l. This water usually has a low chloride content and a fairly low sulphate content. As in the case of the Highveld and Middleveld, there is no truly dominant cation. On the basis of the limited number of analyses of the water of the region, it seems possible to conclude that the water quality is up to the standards of the World Health Organization.

Current studies

In 1986 the Geological Service in co-operation with the Canadian Government began a five-year programme of ground-water exploration. The project covers the whole country and it dealt first with the Lowveld and the Lubombo plateau. The aim is to recognize the accessible ground-water resources and determine their potential and the quality of the water, as well as increasing the capacity of the staff of the Geological Service to undertake future ground-water exploration programmes and data analysis. A terminal report will be presented on the conclusion of the project in 1990.

IV. EXPLOITATION OF THE GROUND WATER

The Geological Survey and Mines Department is the only government service in possession of drilling equipment: two combined rotary/down-the-hole hammer rigs supplied by Canada for the hydrogeological study of the country, and a lighter rotary rig supplied by UNDP for a village water-supply project; this latter rig is used only for utilitarian and humanitarian purposes with little associated hydrogeological research. All the workers are Swaziland nationals and by the end of the programme they will have the necessary technical capacity to conduct the studies and operate the rigs. There is also a second, somewhat older, cable rig. Some drilling is carried out by private firms with compressed-air rigs.

There are eight qualified national drillers, and the drilling capacity of the Government's boreholes section is estimated at about 5,000 m per year.

The ground water is usually used to supply rural areas, including social infrastructures, schools and health and community centres. It is thought that it might also be used to supplement surface water in the supply of the large rural centres which experience periods of water shortage.

Livestock-raising is confined to the Lowveld where there is little surface water. The development of ground water is therefore of great interest in this region. Furthermore, ground water is the only water resource available to State and private enterprises, and the quantities extracted are steadily increasing.

Data collection, drilling for water and installation of wells will be continued at sites with good potential under the auspices of the Geological Service, but it will also be necessary to establish hydrogeological and hydrochemical centres and improve the design of the installations. A better correlation must also be achieved between the geophysical and the geological data.

Since the ground water has not been extensively exploited so far, there are no problems with respect to the effects of pumping on the environment.

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