S ST/TCD/6

Department of Technical Co-operation for Development

Natural Resources/Water Series No. 19

GROUND WATER IN EASTERN, CENTRAL AND SOUTHERN AFRICA

UNITED NATIONS
New York, 1989

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.

ST/TCD/6

UNITED NATIONS PUBLICATION

Sales No. E.88.II.A.5

03950

ISBN 92-1-104223-2

CONTENTS

CONTENTS (cont'd)

Annex

Maps and Figures

CONTENTS (Cont'd)

Maps and Figures (Cont'd)

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.

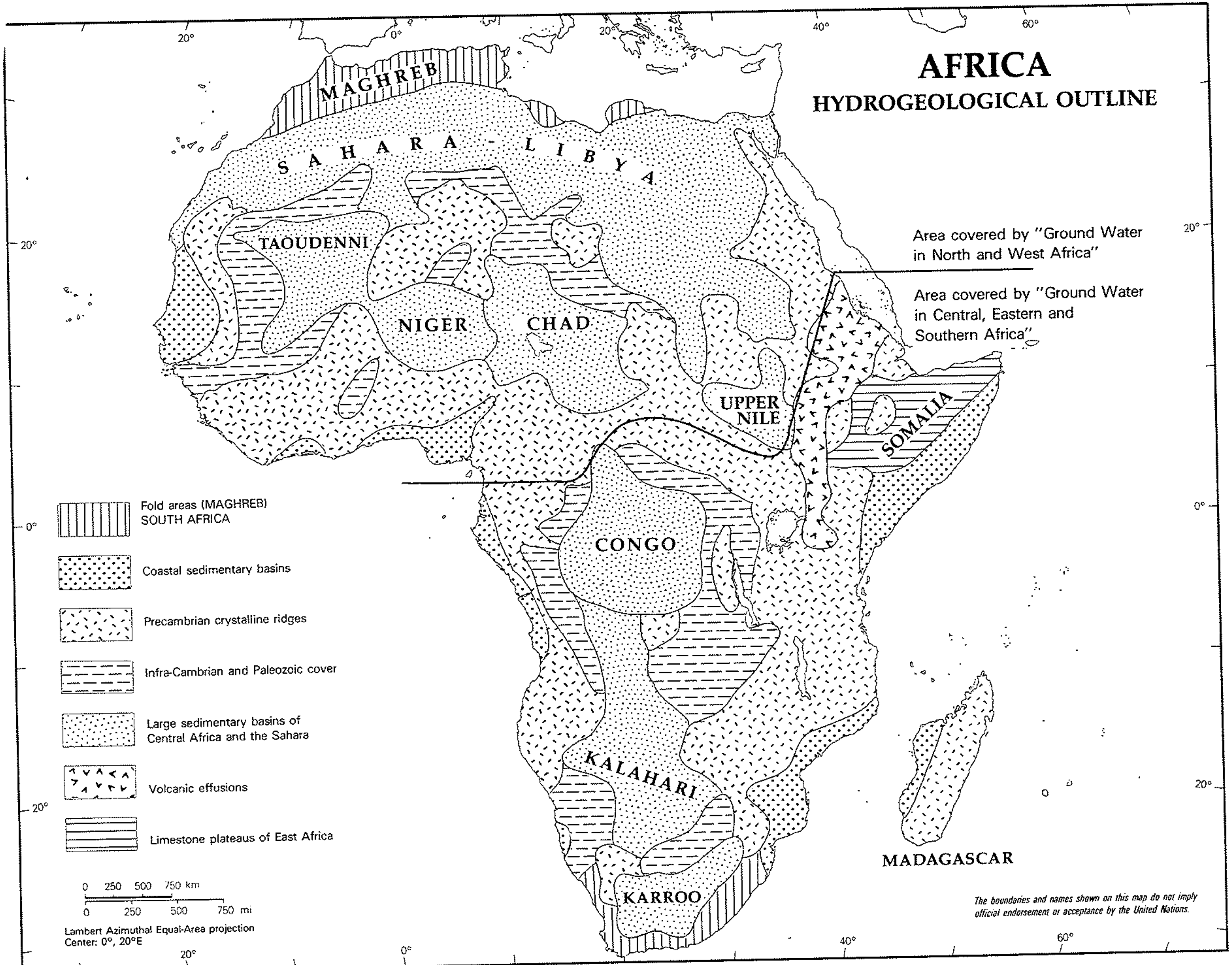
Use of a hyphen (-) between dates representing years, e.g. 1975-1978, signifies the full period involved, including the beginning and end years.

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.



MAP NO.3432 Rev.1 UNITED NATIONS
MARCH 1989

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.

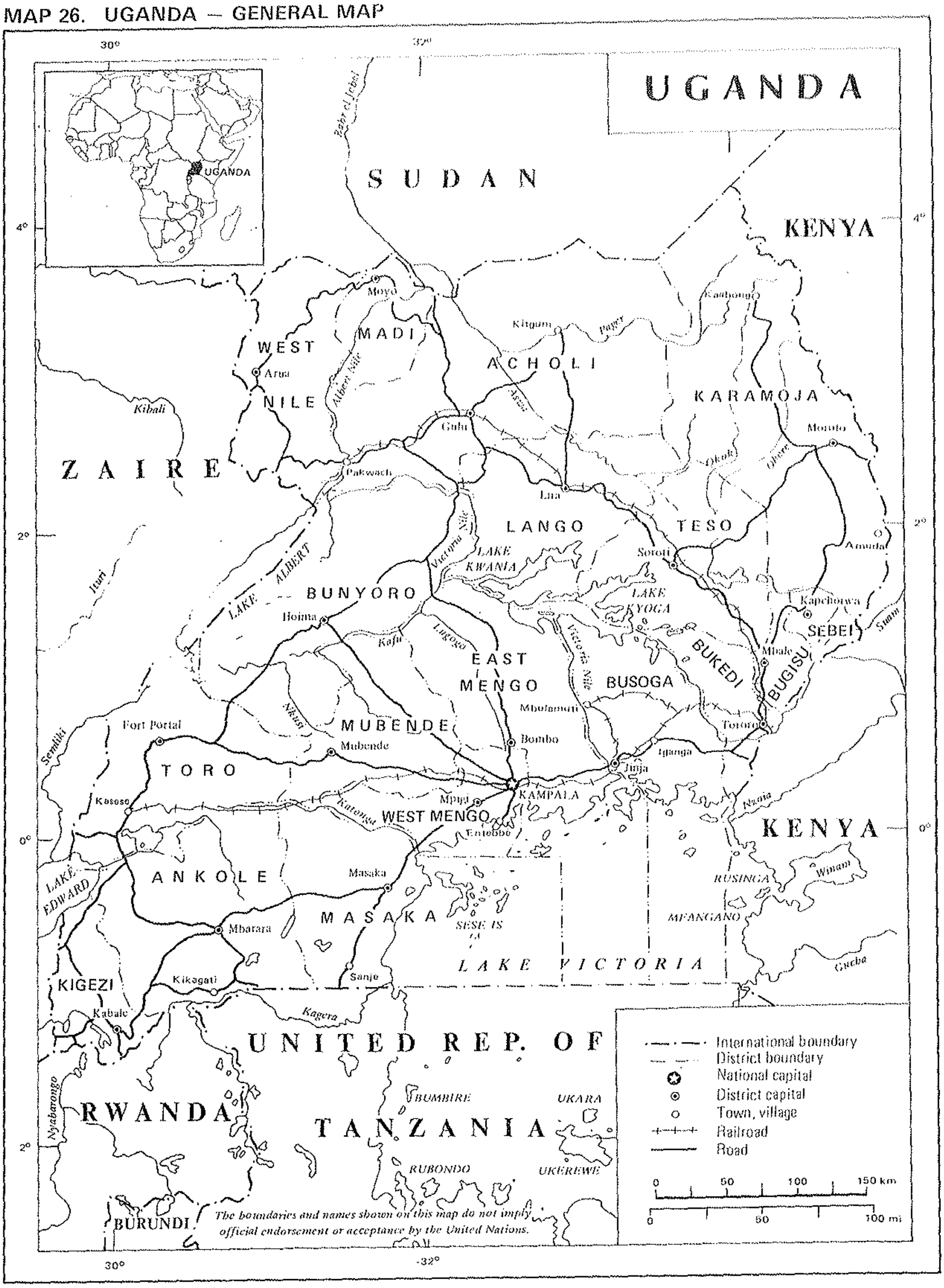
Furthermore, ground-water prospecting and the drilling and digging of wells are usually difficult and expensive operations owing to the weakness of the infrastructures, the unfavourable natural conditions, the remoteness of the zones to be reached and the wide dispersal of the villages, as well as the 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.

MAP 26. UGANDA — GENERAL MAP



MAP NO.3074 Rev.1 UNITED NATIONS
MARCH 1989

UGANDA

Area: 235,800 km^2
Population: 14,6 million

I. BACKGROUND

Uganda is the "water tower" of Central Africa. It consists of high plateaus 900-1,500 m above sea level, 18 % of the area of which is made up of freshwater swamps and lakes such as Lake Victoria, the second largest lake in the world: 69,000 km^2 with a maximum depth of 80 m and a capacity of 2,700 km^2. The other major lakes are Kyoga (5,000 km^2) and George, Edward and Albert (Mobuto, Sesse and Seko).

The country has the following five climatic zones:

- Lake Victoria: Daily variation of 8-11 °C (40-80 km from the shore of the lake); rainfall well distributed throughout the year with maximums in March-April, May and October-November. Annual rainfall on the lake's shores: 1,500-1,800 mm with 160 to 170 rainy days;

- Karamoja (in the north): Altitude 1,070-1,220 m with isolated peaks up to 2,745 m; average annual rainfall 510-750 mm (maximum 1,020 mm); rainy season from April to August with the low point in June and the peak in May and July; December and January are the driest months;

- West Uganda: This is the highest area - 1,220-1,525 m with isolated peaks rising to 2,135-2,440 m and a high mountain (Mt. Ruwensori - 5,090 m); annual rainfall 1,270 mm, with maximums of 1,525-2,440 mm, distributed over 100-150 days; in some areas it is 890-1,000 mm over 80-100 days. The morphology and altitude have a great influence on rainfall;

- Acholi-Kyoga: Plateau area (1,050-1,240 m) with average rainfall of 1,270 mm over 140-170 days. The wet season is from April to October with high points in April-May and August-October. The rain is produced by convection currents and falls in the afternoon and evening;

- Ankole-Buganda: Average rainfall of 1,010 mm over 90-130 days, with high points in April-May and September-November and top dry seasons in June-July and December-February.

Surface water

Uganda has permanent watercourses with clearly established directions of low which are influenced first by the tectonics and then by the geological and geomorphological structures. There are seven main hydrographic basins:

- Lake Edward (1,935 km^2) which receives the waters of the Ntungu, Ishasha and Nyamwere and other streams;

- Lake Victoria (58,161 km^2) which receives the Kagera and the Ruwizi;

- The Victoria Nile (27,773 km^2) with the Kafu and its tributaries, where there are vast swampy areas;

- Lake Albert (16,699 km^2) which receives the Musizi, Nkusi, Wanbabye, Waki and Weiga;

- Lake Kyoga (57,004 km^2), the second largest basin, with the largest swampy area. Its main rivers include the Sezibwa, Victoria Nile, Okere, Okok, Akweng, etc. The waters of this lake discharge into the Victoria Nile;

- The Aswa, a tributary of the White Nile (26,558 km^2): its main watercourses include the Pager, Agago, Aswa, Nyimur and Ateng;

- The Albert Nile (19,773 km^2): the main tributaries are the Ome, Aswa, Tangi, Ora, Ala, Anyau, Kochi, Jurei and many others. Most of these rivers rise in the West Nile Hills. The low areas along the Nile include 5,600 km^2 of swamp. There are about 704 dams and artificial reservoirs of various sizes.

II. GEOLOGY

Most of the country is covered by crystalline rocks of the Precambrian basement. Volcanic rocks and Cretaceous sediments are also found in the east and west of the country. Between these two systems, which are 460 million years old, lie the Karroo argillaceous schists.

- The crystalline basement includes gneiss, granulite, metamorphic schists, and marbles, with acid and basic intrusions. The rocks are of various ages and the degree of metamorphism also varies; its most recent manifestation dates to about 500 million years ago;

- Nyanzian and Kavirondian systems. The Nyanzian system overlies the crystalline basement and consists of acid or neutral volcanic rocks. The Kavirondian system consists mainly of rhyolites, porphyry, tufa and basalt, with some conglomerates;

- Toro-Buganda system. This system outcrops in the south-north of Lake Victoria and south of Lake Albert. It consists of schists, phyllites and micaschists. Large amounts of quartzite occur in the north and west of the system. The Kyoga and Bwanba series and the Madi quartzites rest in discontinuity on the basement. The rocks are tightly folded and intensely metamorphized and granitized in some places;

- Karagwe-Ankolean system. This system is found in the south of Uganda, resting in discontinuity on the Toro-Buganda system; it includes several formations of argillaceous origin such as schists, slates and tillites. There are large amounts of sandstones and quartzites which, together with conglomerates, reach great thicknesses in the north, while in the south they are represented by poorly sorted clay-sand schists and argillaceous sandstones. Dome-shaped granitic structures are found here. The "arenas" - residual-erosion structures - consist of circular granitic areas ringed by hills of sedimentary rocks;

- Singo series. These series overlie the Buganda series of the Toro system and consist of conglomerates and sandstones;

- Bunyoro series. These series include argillaceous schists and arkoses with tillites at the base. They probably date to the end of the Precambrian;

- Bukoba system and Mityana series. Small outcrops of the Bukoba system are found in Uganda. They consist mainly of fine sandstones resting in continuity on the Karagwe-Ankolean system on the western shores of Lake Victoria. The Mityana series include arkosic conglomerates and silicified rocks resting in discontinuity on the Singo series;

- Paleozoic. This period is represented by the Karroo clay-schist formations which outcrop in a few places at Entebe and Birgiri and on Dugusi Island;

- Mesozoic. This period is represented by isolated circular masses of carbonatites associated with alkaline rocks, probably of Cretaceous age, in the east of the country;

- Cenozoic. This period is represented by volcanic rocks in the region of Lake Kyoga north of Mt. Elgon: alkaline basalts, phonolites, nephelines, trachytes, alkali-rhyolites and their pyroclastic equivalents. Kisegi and Kaiso strata of Miocene to Lower Pleistocene age are also found in the area of Lake Albert. These strata are confined to the western Rift Valley and are sometimes overlain by the Semliki series formed of products from the edge of the Rift. They are about 2,500 m thick;

- Quaternary. These are Pleistocene to Recent alluvial deposits along the valleys of the watercourses, lacustral and swamp deposits, and deposits on the floor of the Rift Valley. They are found east and west of Lake Kyoga along the courses of the Mpologoma, Sezibwa and Katong-Kagera, and along the north-west shores of Lake Victoria.

Pleistocene to Recent volcanic formations are found only in the south-west of the country.

- Intrusions. These are granites, apparently of post-Nyanzian age;

- Laterizations. Laterites are found in large areas of the country, but more particularly in the Buganda region, some parts of western Uganda, and in the Kyoga area. They originated in several cycles of surface erosion which occurred in the region from the Cretaceous period. Several hills are topped with the remnants of a lateritic crust;

- Structure. It is usually difficult to identify the faults, for there are few outcrops of bare rock. However, several ancient faults are marked by quartz or tectonite veins formed by silification of shear zones.

There are two main structures: the Aswa shear zone and the western Rift Valley. The first structure is indicated by mylonites which run from the south-east into Sudan.

The Rift Valley contains several lakes and the horst of the Rwenzori mountains. The displacement is about 3,050 m and the sediments are 1,830-2,440 m thick. The Rwenzori mountains consist of a raised block of ancient rocks bounded in the west by a large fault and in the east by the Lake George depression.

The gneissic basement and its overlying Precambrian rocks generally run northwards, with a few local deviations.

III. HYDROGEOLOGY

The systematic study of ground water began in 1920. The hydrogeological work, including drilling, was entrusted to the Geological Survey and Mines Department, but this Department gave priority to traditional geological activities - mainly cartography - and mining exploration. This is why it was not furnished with the professional hydrogeological capacity needed to meet the demand. As a result, the Government decided in 1977 to establish a single body to carry out hydrogeological studies and water drilling which was subsequently strengthened. The administrative structure is as follows:

Ministry concerned: Land and Resources

Department: Water Development, which has the following divisions:

- Planning, projects and documentation;
- Construction and development (including a drilling section);
- Operation and maintenance;
- Mechanical (workshop);
- Water resources, which has the following sections/subdivisions:
  - Hydrology;
  - Water quality and pollution control;
  - Research and training;
  - Hydrogeology.

The hydrogeology section has the following responsibilities:

- Ground-water development in rural areas, mainly to meet the needs of rural communities, official services, agriculture and livestock;
- Evaluation of Uganda's ground-water resources: collection, analysis, inventory and interpretation of hydrogeological data, with the specific goal of preparing a hydrogeological map.

Owing to the lack of personnel and material means, the hydrogeology section has so far completed very little of this work.

The hydrogeological data collected include field-reconnaissance observations, interpretation of aerial photographs, well logging, measurement of water tables, and hydrochemical analyses. Uganda has about 5,000 boreholes, most of them equipped with hand pumps and only a few with motorized pumps. They are fairly well distributed throughout the country, but their number is not considered sufficient.

The activities planned for the future are designed to meet the water needs of the rural population. The drilling section must be strengthened, particularly with respect to equipment and spare parts. Once the current reorganization of the services is completed, the geophysics subsection of the hydrogeology section will be responsible for drilling and logging of boreholes. Satisfactory results have already been obtained with the seismic refraction method. Logging is also expected to solve many of the problems, such as those relating to transitional zones between one formation and another. Geo-electric methods will also be used for the detailed study of alluviums and the altered zones of the basement.

Aquifers

There has been considerable study in Uganda of yields, the depth of boreholes, the hardness of the rocks, and the altitude of boreholes (absolute altitude or altitude in relation to the valley floor), for these factors have a major impact on borehole cost, either per linear metre or per installation. Several authors have demonstrated clearly that the yield is highest in boreholes 30-90 m deep, with a considerable decline beyond 100 m, and that the yield is related to the hardness of the rock. The degree of alteration of the rock is therefore an important factor. Three types of alteration are found in Uganda:

- Uncohesive decomposed rocks which appear as mud in the drilling liquid. These are soft materials filling the joints and producing virtually impermeable zones which place the underlying water-bearing zone under pressure. They occur in pockets identifiable by the resistivity prospecting method. They run parallel to the direction of the underlying rocks. Drilling in these decomposed zones is therefore uneconomical;

- Cohesive altered rocks which appear in the drilling liquid as sands with identifiable grains indicating the parent rock. Many joints with higher porosity are found in these rocks;

- Solid rock without apparent alteration, where ground water is sometimes found in the deep fissures, with generally low yields. It should be noted that the use of explosives usually results in a lower yield. No relationship has been established between the yield and the depth of the well or between the yield and the difference in level between the well and the valley floor.

The water-bearing properties of the hard rocks depend on the degree of fracturation and jointing of the layers, hence the importance of identification of these features for the development of ground water in Uganda.

Analysis of aerial photographs and electrical sounding and resistivity profiles have been used successfully in the study of the ground water of Karamoja. Seismic refraction has also been used with excellent results in the identification of areas of low wave velocity corresponding to areas where the wells have higher than average yields.

Intensive ground-water research has been carried out in Karamoja, an arid region inhabited by herdsmen who are in the process of becoming sedentary, under a project of the United Nations Special Fund executed by the United Nations between 1965 and 1968. Major resources were mobilized for this project: 4 hydrogeologists, 1 hydrologist, 2 geophysical teams and 6 drilling rigs operated by experienced engineers. This was the largest integrated ground-water study operation ever carried out in Eastern Africa.

Between 1932 and 1965, about 490 boreholes were drilled in the Karamoja region, of which 256 were exploited (209 by hand pumps, 47 by motorized pumps). It is estimated that the minimum exploitable yield is 0.5 m^3/h for a hand pump and 4 m^3/h for a motorized pump. The annual recharge of the ground water is about 30 million m^3/year. Most of the water has a salt content of 300-900 ppm.

The drilling operations carried out under the Special Fund project included 92 reconnaissance boreholes totalling about 10,000 m. Sixty-nine of these installations are productive and 36 can be equipped with motorized pumps. The average yield is 8 m^3/h, with a maximum of 70 m^3/h. The best yields have been obtained from boreholes 45-90 m deep (beyond 100 m the yields are poor) and from the flat floors of valleys dominated by steep-sided hills.

The water resources identified in these operations are sufficient to meet the requirements of the people and their livestock but, except in a few cases, they are not suitable for irrigation owing to their high cost and the poor unit yields.

Available yields

- Precambrian rocks. Boreholes in these Ancient formations, which occur extensively in the country and include intrusive granites, yield 0.35 to 5 m^3/h. The highest yields are obtained from fissured rocks with developed joints: quartzites, granites, gneiss and marbles. The phyllites and slates yield very little water;

  The granites and gneiss have poor permeability in the lateral direction, for the joints are not aligned, the aquifers are quite local and small, and the recharge is local and produced by direct infiltration. The porosity is estimated at 1 % of the rock and the recharge is effected through the soil cover (and not in the thick clay soils);

- Karroo argillaceous schists. The Ecca schists outcrop over a small area and have very poor aquifer properties;

- Cenozoic carbonatites. The properties of these rocks are not known. They are thought to be similar to those of the granites and related types;

- Cenozoic and Pleistocene. The tufas and some of the conglomerates (Bufumbira and Karamoja) are very poor aquifers. However, it should be noted that there are some volcanic rocks of this type which have not been exploited for their ground water owing to their topographical position, whereas the same rocks are major aquifers in neighbouring countries, including Kenya;

- Rift Valley sediments. These sediments are about 1,200 m thick in some places. They furnish yields of about 0.5 m^3/h, although some boreholes have proved barren. Certain sediments produced by the modification of coarse deposits give better yields, but they cover a smaller area. The best aquifers are thought to be located at depths of 200-300 m. Their water may have a fairly high mineral content;

- Pleistocene sands and gravel fills. These are important aquifers but they are found only in small pockets where the high pore velocity prevents the deposit of fine materials. Sandy laterites have also furnished fairly high yields, for example at Kyajjanga and in some parts of the Isingiro valley.

To sum up:

- In the Kyoga basin boreholes 45-76 m deep have yielded 0.5 to 1,85 m^3/h, but some of them which achieved sufficient penetration of developed fissures and fractures in communication with each other have yielded up to 5 to 7 m^3/h. In the Lake Albert area ground water has been found at depths of 45-140 m in the gneiss of the crystalline basement, with yields of 1.4 to 3.7 m^3/h. The sediments of the Rift Valley have lower yields than expected in comparison with those of the Precambrian rocks, i.e. 1.8 to 4.2 m^3/h: the water table is virtually at lake level;

- In the Lake Victoria region the yields are 0.5 to 1 m^3/h whatever the formation. About 8.5 % of the boreholes are barren; 6 % yield 0.5 m^3/h.

Water quality

The dry residue is in the order of 200-800 mg/l, i.e. higher than for the water of the rivers and lakes. Bicarbonate is the main anion, and the chloride and sulphate contents are small in comparison. Calcium and sodium are the main cations. However, magnesium is found instead of calcium in some cases. The pH value of the ground water is 6.5 to 8.9 and there are no problems with respect to colour and smell. However, the ground water obtained from the gneissic complex or other Precambrian crystalline rocks can be more saline. In the area north of Lake Victoria the ground water has a salt content of 200-800 mg/l. Fluorides are not a problem in Uganda, for they are found in much smaller quantities than in Kenya and Tanzania. Most of the ground water is therefore suitable for domestic and agricultural purposes, for its salt content is little different from that of the surface water.

The main problem with respect to the water's chemical composition is that of fecal pollution in Lake Kyoga and in Karamoja where the ground water aquifer rises almost to surface level in the rainy season. This problem is a major one in all places where the boreholes draw pumped water from a surface aquifer close to the soil and liable to pollution.

IV. REFERENCES

Bisset, C.B., Acceleration and extension of water supply. Report on water supplies in part of Masaka district, 1936.

__________, Summary report on water supply conditions in the Suk area of Karamoja, 1938.

__________, Water boring in Uganda, 1920-1940. Geological Survey, Uganda, water supply paper No. 1, 1941.

__________, Water supplies: Application to the Colonial Development Advisory Committee. Geological Survey of Uganda, 1939.

Dijon, R., The search for ground water in the crystalline regions of Africa. Natural Resources Forum, Vol. 1, United Nations, New York, 1971.

Dyke, L.J., Observations on the value of electrical resistivity measurements in sitting boreholes for water in Uganda. Geological Survey of Uganda, report LJD/28, 1955.

Faillace, C., Location of ground water and the determination of the optimum depth of wells in metamorphic rocks in Karamoja, Uganda. Atti del 2° Convegno Internationale salle Aque Sotterranee, Palermo, 28 April-2 May 1973.

__________, Geochemical Atlas of Uganda. Geological Survey and Mines Department, Uganda, 1973.

Gear, D.J., Underground water supplies in the granitic and gneissose rocks of Eastern Uganda, October 1951.

__________, The electrical resistivity problem in the location of groundwater in the decomposed igneous and metamorphic rocks of Uganda and Sudan. Ph.D. Thesis, London University, 1955.

Gould, D., Water boreholes in Uganda and their spatial distribution. Geological Survey of Uganda, report DG/10, 1971.

Harris, N., Geophysical survey for ground water in Karamoja, Uganda. UNDP/Terratest, Stockholm, 1966-1968.

__________, Karamoja ground-water survey - preliminary statement prepared by the United Nations as participating and executing agency for the United Nations Development Programme, New York, December 1968.

Hepworth, J.V. (with E.R. Biggs), Investigation into the dry boreholes in the Rift Valley area of West Nile. Geological Survey of Uganda, unpublished report JVH/16, 1961.

Loayland, E.J., Soil erosion and water supplies in Uganda. Geological Survey of Uganda, Memoir No. IV, 1938.

MacDonald, R., Water borehole sitting in Uganda. Geological Survey and Mines Department, Uganda, 1971.

McCann, D.L., The role of ground-water discharge in the water balance of lakes, in Hydrometeorological Survey of the Catchments of Lakes Victoria, Kyoga and Albert. RAF 66 - 025 technical report 1. UNDP/WMO, Geneva, 1974.

Way, H.J., Geophysical prospecting for water in Uganda. Mining Magazine, Vol. LXV, 1941.

__________, Rural water supplies, policy, progress, planning, 1950.

Geological maps

These maps have been drawn on scales of 1:50,000 and 1:250,000. They cover the following areas:

- Most of Bunyoro and the areas north of Lake Kyoga;
- The area south of the first parallel N;
- The Karamoja and West Nile regions;
- The region bordering Kitgum in northern Uganda.