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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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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

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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.

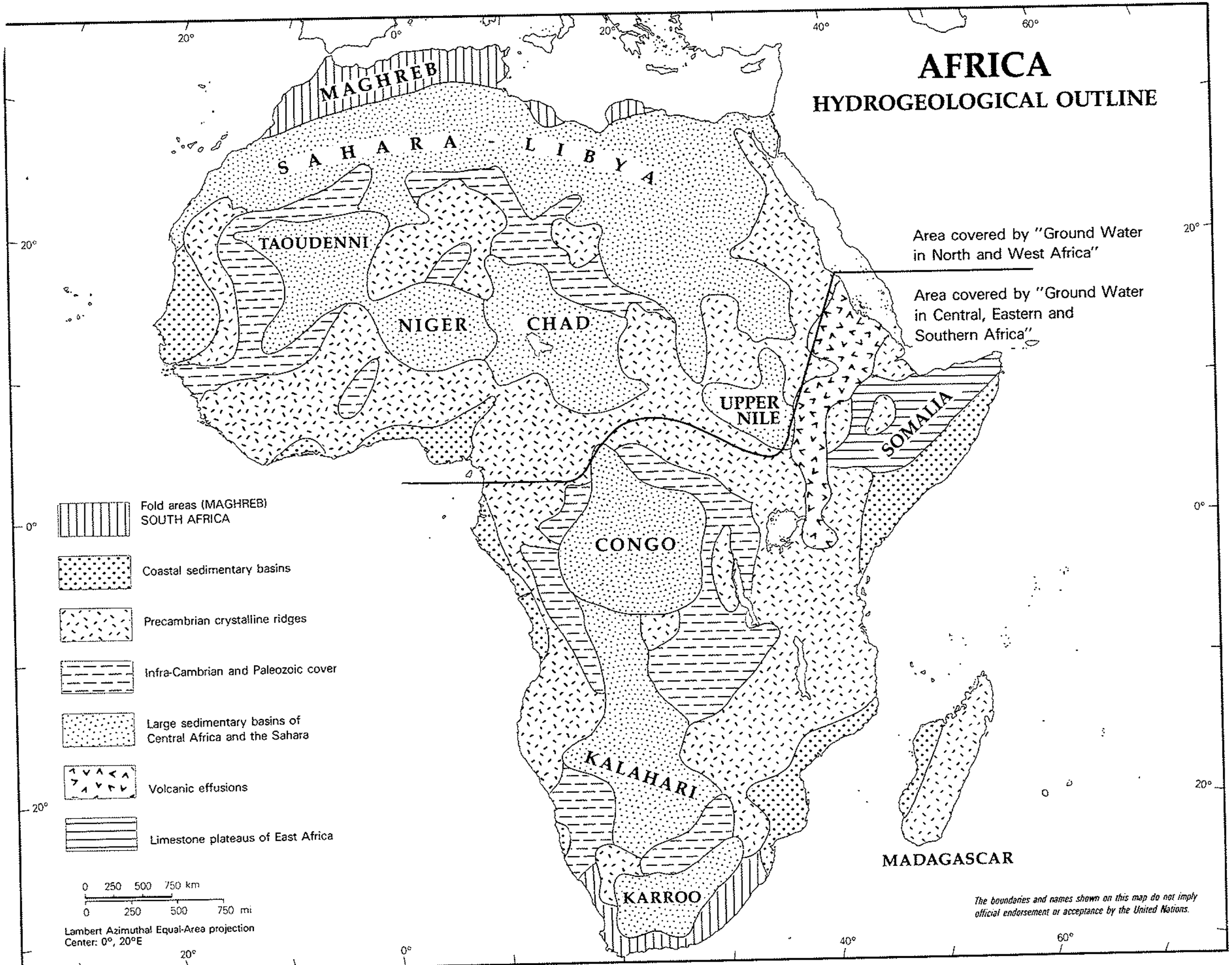
Use of a hyphen (-) between dates representing years, e.g. 1975-1978, signifies the full period involved, including the beginning and end years.

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.



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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.

ZAIRE

Area: 2,345,400 km^2
Population: 31 million

I. BACKGROUND

Physiography

The centre of the country consists of a depression covering 750,000 km^2 and ranging in altitude from 340 to 700 m above sea level.

This basin is bounded in the north by the watershed of the Oubangui River, in the east by the mountain ridge which marks the edge of the African Rift, in the south and south-east by the Kasai and Shaba plateaus, and in the west by the Mayumbe hills. The landscape is tranquil, consisting of broad steep-sided valleys set between very flat interfluves in the south-east and regular dry terraces with abrupt walls in the west. The limit of the depression corresponds almost exactly with that of the equatorial forest.

The Kasai plateaus are about 1,000 m above sea level and covered with wooded savannah intersected by areas of forest.

The high plateaus of Shaba are between 1,400 and 2,000 m above sea level and are covered with thinly wooded savannah. The Mayumbe hills are 750 m high on average and form a system of hills linked by narrow cols with a tangled network of valleys. These hills carry a continuation of the great Gabonese forest with its various species.

The mountain ridge in the east, which is between 2,300 and 3,800 m above sea level, marks the edge of the Great African Rift, 1,400 km long and 40 km wide. This trench contains Lakes Tanganyika, Kivu, Idi Amin and Mobutu.

The coastal area around Banana (Atlantic Ocean) consists of either low areas and vast sandy beaches, or cliffs.

Climate

The country is crossed by the equator. The average annual temperature is 25 °C at the coast, and 24-25 °C in the north, the central basin, North-Shaba, Kasai, Kinshasa and Bas-Zaire. In the mountainous regions of the east where the altitude is higher, the average annual temperature is 19-20 °C. The highest average temperatures occur in March or April in the north of the country, the central basin and Bas-Zaire, in September in southern Kasai and North-Shaba, and in October in South-Shaba. The annual temperature range is generally very small: 2 °C between the hottest and the coldest months. But the daily range is high in the low regions: 9-11 °C in the wet season.

Owing to the cloud cover, the equatorial region has less sunshine (2,000 hours a year) than the tropical regions (2,700 hours a year in southern Shaba). The maximum sunshine occurs in the dry season: 225-250 hours a month in January in the north and 300 hours in July in the south. The minimum occurs in the rainy season: 150 hours in July and August in the north and 125 hours in January in the south.

The country is traversed by four types of airflow:

- The south-west current or Atlantic monsoon is cool wet air flowing at altitudes below 1,500 m. This current is the main source of humidity;

- The very hot and dry north-east prevailing wind blows from the Sudan during the northern dry season;

- The cold dry south-east prevailing wind blows during the southern dry season;

- The eastern equatorial flow, which is hot and dry, comes from the Indian Ocean and is virtually permanent above 4,000 m.

The annual precipitation is over 1,200 mm for the whole country. The centre of the basin receives more than 2,000 mm and the rainfall declines with distance from the equator. The maximum rainfall occurs on the western slopes of the eastern mountains and the minimum at the coast (Banana - 840 mm).

Zaire has two seasons: the rainy season which runs from September to June in the south and from February to November in the north; and the dry season in December and January in the north and June and July in the south.

The maximum humidity (over 85 %) occurs in the central basin and declines with distance from the equator. It ranges from 70 to 80 % in the mountain regions.

Hydrography

The Zaire River which crosses the country drains all the surface water. It is 4,700 km long and its basin covers an area of 3,822,000 km^2; it is thus the largest basin in Africa and the second largest in the world after the Amazon River (6,300,000 km^2). The basin extends on both sides of the equator and occupies the central part of the African continent.

The main tributaries of the Zaire are:

- Left bank: Lubudi, Lomami, Lulonga, Ruki, Kwango, Kasai;

- Right bank: Lufira, Luvua, Lukunga, Luana, Ella, Ulindi, Lowa, Malko, Lindi, Aruwimi, Itimbiri, Mongala, Oubangui, Sangha, Aftma, Foulakary and Djue.

The flow of the Zaire River has been measured at several points:

Banana:	40,684 m^3/s
Kinshasa:	38,844 m^3/s
Kisangani:	6,378 m^3/s
Bukama:	322 m^3/s

Most of the rivers of the central basin are navigable. At the edges of the Zaire basin the rivers have waterfalls where dams have been constructed for hydroelectric power stations.

Table 1

Flow of the basin's main rivers

River		Measuring station Name	Longitude	Latitude	Period of observation (since)	Mean annual flow 1950-1959 (m^3/s)	Total average annual flow 1950-1959 (mm)
1.	Zaire River	Bukama	25° 51' 35" E	9° 11' 35" S	1933 -	322	161.14
2.	Zaire River	Kindu	25° 55' 45" E	2° 57' 10" S	1912 -	2,213	86.08
3.	Zaire River	Kisangani	25° 11' 30" E	0° 30' 20" N	1907 -	6,378	206.58
4.	Zaire River	Kinshasa	15° 18' 30" E	4° 17' 45" S	1925 -	38,844	327.08
5.	Zaire River	Boma	13° 03' 00" E	5° 51' 30" S	1915 -	40,684	335.87
6.	Inkisi	Inkisi (bridge)	15° 04' 05" E	5° 07' 45" S	1949 -	-	-
7.	Foulakary	Kimpanzu	14° 56' E	4° 36" S	1950 -	54.5	570.74
8.	Kasai	Ilebo	20° 34' 55" E	4° 20' S	1922	2,240	303.94
9.	Kasai	Kutu Moke	17° 20' 45" E	3° 11' 50" S	1932	8,790	376.50
10.	Kasai	Lediba	16° 33' 25" E	3° 03' 25" S	1932	11,318	406.50
11.	Kwanko	Bandundu	17° 22' 15" E	3° 17' 55" S	1929	3,299	396.02
12.	Oubangui	Bangui	18° 35' 45" E	3° 21' 30" N	1911	4,024	253.98
13.	Sengha	Onesso	16° 05' E	1° 39' N	1947	1,763	351.69
14.	Itimbiri	Aketi	23° 50' 20" E	2° 42' 45" N	1928	356	353.88
15.	Shari	Budana	30° 09' 35" E	1° 35' 55" N	1937	33	250.63
16.	Lomami	Opala	24° 21' 10" E	0° 36' 10" S	1917	2.98	429.37
17.	Lukunga	Kalemie (bridge)	28° 12' 10" E	5° 54' 40" S	1952	-	-
18.	Ruzizi	Bukavu	28° 53' 32" E	2° 29' 25" S	1950	-	-
19.	Luvua	Kiambi	28° 00' 45" E	7° 20' 15" S	1935	669	85.96
20.	Luapula	Kasenga	28° 36' 55" E	10° 21' 35" S	1934	616	119.96
21.	Lufira	Kapolowe	26° 57' 40" E	11° 02' 40" S	1920	49	190.72

Geology

Zaire has two large geological systems separated by a discontinuity and/or major hiatus: the non-metamorphic surface formations have remained horizontal and are generally fossiliferous, dating from the Upper Carboniferous to the Holocene; the formations of the Precambrian basement are variously metamorphized and folded. The country also has the following "geological zones":

- A coastal zone between the Atlantic Ocean and the Mayumbe hills with marine formations of Cenozoic and Cretaceous age;

- The central basin which contains deposits of Mesozoic and Cenozoic age;

- The edge of the Precambrian formations, subdivided into four tectonostrategic units.

The formations of each of these zones are variously covered wholly or in part by:

- Recent formations with various facies;

- The "ochre sands" series and the "polymorphic sandstones" series which extend over vast areas of the southern half of the country.

II. GROUND WATER - BACKGROUND

The following are the government services and other organizations concerned with water resources in general:

Department of Mines and Energy: drinking water and hydroelectric power;

Department of Agriculture and Rural Development: drinking water in rural areas, irrigation water, drainage;

Department of the Environment: drinking water quality;

Department of Transport and Communication: navigable waterways;

National Action Committee for Water and Sanitation.

The government services specializing in ground-water study and evaluation are: REGIDESO, the Faculty of Sciences, the Department of Geology at Lubumbashi, the Geological and Mining Research Centre (CRGM).

Zaire has not so far carried out any systematic hydrogeological prospecting; the only hydrogeological data are those produced by mineral prospecting in the various regions of the country and they have been used only to make good the shortage of surface water, especially in the regions where intense drought causes rapid evaporation. More recently, ground water research has been carried out in several places with a view to supplying the people with drinking water. This is the case of the main urban areas, which are found both in the central basin (for example, Boende, Lisala, Basankusu, etc.) and in the areas where the Precambrian formations consist essentially of limestones (Mbanza-Ngungu, Likasi, Lubumbashi).

The research methods used have been interpretation of aerial photographs and of the results of drilling for minerals, and to a lesser extent geophysical prospecting.

Table 2

Description of existing wells in Zaire
Consolidated and non-consolidated sedimentary formations

No.	Location	Geographic co-ord. Longitude	Geographic co-ord. Latitude	Aquifer Formation	Aquifer Thickness (m)	Depth of well (m)	Hydraulic properties: Specific yield: m^3/h per m of drawdown	Hydraulic properties: Permea-bility K (m/d)	Hydraulic properties: Transmis-sivity T (m^2/d)	Hydraulic properties: Storage coefficient S (%)
1.	Mbanza-Ngu (F1)	14° 50' E	5° 16' S	Precambrian karstic fissured limestone	82.5	152	11	1.583	130.6	0.3×10^{-5}
2.	Mbanza-Ngu (F2)	14° 50' E	5° 16' S	Idem	45	117	12	3.072	138.2	0.3×10^{-5}
3.	Kikwit (P3)	18° 49' E	5° 18' S	Cretaceous soft sandstones with layers of argilites		160	4	1.296	129.6	6.5×10^{-4}
4.	Kikwit (P6)	18° 49' E	5° 18' S	Idem		201	3.1	0.604	103.68	2.6×10^{-4}
5.	Moanda	12° 22' E	5° 56' S	Coarse sands	10	93.8	1.52	8.64	86.4	5×10^{-4}
6.	Likasi (Kikula)	26° E	10° S	Precambrian dolomitic limestones	40	202	3.3	-	-	-
7.	Luiza	22° 30' E	7° 11' S	Precambrian coarse sands and clay gravels	15	94	0.1	-	-	-
8.	Bolobo	16° 14' E	2° 9' S	Fine to coarse white sands	7	38	6.8	5.69	39.83	1.65×10^{-3}
9.	Ikela	23° 10' E	0° 1' 10" S	Clay sands and sandy clay	13	53	6.45	16.615	216	3.8×10^{-4}
10.	Luebo	21° 22' E	5° 22' S	Sands and gravels	3	20.5	10.08	36.67	290	0.1

N.B. This list is not exhaustive as it is not possible to list the properties of all the wells in Zaire.

On the basis of the interpretation of aerial photographs the National Welfare Fund (FBI) carried out a vast well-drilling programme with a view to supplying drinking water to the rural centres in the plateaus region.

The following water-bearing formations have been identified:

Coastal zone: Residual sands of sublittoral sandstones, granitic sands north of Boma.

Central Basin: Lateritic gravels, fine to coarse sands, soft fine to coarse sandstones. The aquifers in the sandstone are situated at great depths below the Kwango plateaus.

Precambrian formations: Sand-clay alluviums in the shallow strata; dolomitic limestone formations in the karstic strata.

REGIDESO is currently carrying out feasibility studies of several locations in the country with a view to supplying them with drinking water. These studies are carried out either by REGIDESO's own personnel or by consulting engineers. They are available for inspection at REGIDESO.

In most of the locations it is ground water which is selected as the resource to be developed. The implementation of the water-supply projects will provide an opportunity for acquiring more detailed knowledge of ground-water.

III. EXPLOITATION OF THE GROUND WATER

REGIDESO is responsible for the development of ground water to supply urban dwellers. It has the following general organization and structure:

1. A governing Council with seven members;

2. A Management Committee consisting of the Président-délégué-général assisted by two chief administrators and a staff representative. As delegated by the Governing Council, the Managing Committee administers REGIDESO's current activities, especially with respect to the preparation of economic and financial accounts and the implementation of the Council's decisions;

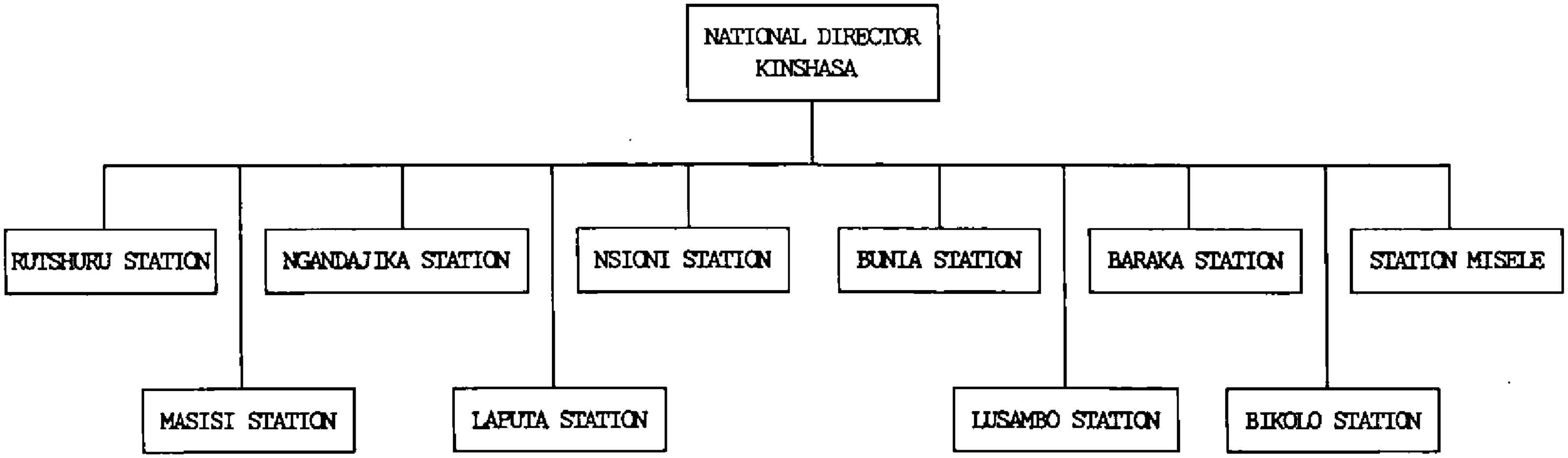
3. Central and regional offices, corresponding to the country's geopolitical composition.

REGIDESO has eight regional offices and two headquarters offices distributed in accordance with the country's political subdivisions which supervise 59 operational centres or stations, each with its own operational area.

There is a regional office at Kinshasa and in the regions of equator, Bas-Zaire, Kasai Oriental, Kasai Occidental, Haut-Zaire and Shaba, and two headquarters offices at Banfundu and Kamina.

Tableau 3

Structure of the National Rural Water Service



The National Rural Water Service is responsible for rural and village water-supplies.

The National Rural Water Service is responsible for the needs of rural dwellers.

Zaire has the following water-drilling organizations:

REGIDESO which has:

3 percussion rigs
1 rotary rig
Drilling capacity: 1,000 m to be drilled in 1985
Drillers: 5 (3 civil engineers, 2 technicians)
Hydrogeologists: 6

Four private companies:

SOTRAF (Société de grands travaux africains) at Kinshasa
SOZAGEC (Société zaïroise de génie civil) at Kinshasa
C.D.I. (Integrated Development Centre)
FORAKY

The following places use ground water extracted by standard and deep wells:

1. Deep wells (boreholes)

Region and place	Number	Diameter (mm)	Depth (m)	Yield (m^3/h)	Drawdown (m)
Kinshasa					
Kinkole	1	300	17.40	50	
Bas-Zaire					
Inkisi	6	250	16 to 21	40	0.04
Equateur					
Bokungu	2	250	111.75	4	
Shaba					
Likasi	1	500	205	300	2
Kasenga	3	200	30 to 33.5	22	1
Kamina	4	150	18 to 29	15	4
	2	200	18	15	3
	1	300	18	15	3
Bandundu					
Masi-Manimba	2			15	

2. Large diameter wells

Region and place	Number	Diameter	Depth (m)	Yield (m^3/h)	Drawdown (m)
Bas-Zaire					
Mbanza-Ngungu	1	2.9	3.80		
Inkisi	1	1	16	40	

Region and place	Number	Diameter (mm)	Depth (m)	Yield (m^3/h)	Drawdown (m)
Equateur					
Lisala	1	0.80	3.8	50	
Libenge	2	2.90	5.03	15	
		1.00	6.10	15	
Boende	2	0.80	7.2 to 8	30	
Shaba					
Kabongo	1	2	6	7	
Kasai-Oriental					
Lusambo	6	1.50	6 to 8	11	

3. Resurgences and springs

Region and place	Number	Diameter (mm)	Depth (m)	Yield (m^3/h)	Drawdown (m)
Kinshasa					
Mutendi	1			60	
Bas-Zaire					
Kimpese	1			< 200	
Mbanza-Ngungu	1			18	
Shaba					
Lubumbashi	3			< 5,000	
Sandoa	1			8	
Dilolo	1			25	
Malemba-Nkulu	1			8	
Moba	1			20	
Kolwezi	1			(GCM)	
Kipushi	1			75	
Kasumbalesa	1			15	
Kivu					
Bukavu	13			15	
Uvira	2			12	
Kasongo	1			15	
Butembo	2			35	
Bandundu					
Kenge	1			25	

Region and place	Number	Diameter (mm)	Depth (m)	Yield (m^3/h)	Drawdown (m)
Haut-Zaire					
Kisangani	3			30	
Bunia	1			45	
Watsa	2			15	
Buta	1			8	
Kasai-Oriental					
Mbuji-Mayi	1			14,000	
Kasai-Occidental					
Mweka	2			80	
Tshikapa	5			60	

Problems:

Most of the installations are old and their yields do not meet the people's needs. In most place, new installations are needed to meet future needs.

Under construction (1985)

Location	Station	Number	Diameter (mm)	Depth (m)	Yield (m^3/h)
Equateur	Ikela	4	200	53	16
	Bolomba				
	Djolu				
Bandundu	Bulungu	3	200		
	Bolobo	2	200	40	15
Kasai-Oriental	Lodja				
	Kole				
	Katako-Kombe				
	Lomela				
	Lusambo				
Kasai-Occidental	Luebo				
Haut-Zaire	Opala				
	Ubundu				
	Irumu				
Bas-Zaire	Muanda				
	Mbanza-Ngungu				

IV. CONCLUSION

After a slow start, the study of ground water in Zaire seems to be developing fairly rapidly with the drinking-water programme which is being carried out under the International Decade for Drinking Water Supply and Sanitation. However, hydrology is generally considered from the practical angle of construction work, for it is responsibility of the State bodies responsible for urban and rural water-supply installations.

It will certainly be necessary at a later stage to consider strengthening the data collection, storage and utilization system and to provide facilities for scientific study of the results obtained, with a view to evaluating the ground-water potential and incorporating the evaluation in the planning of water resources development for the whole country.

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