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GOVERNMENT OF KENYA

SECTORIAL STUDY AND NATIONAL PROGRAMMING FOR COMMUNITY AND RURAL WATER SUPPLY, SEWERAGE AND WATER POLLUTION CONTROL

REPORT No. 7

GROUND WATER RESOURCES IN KENYA

WORLD HEALTH ORGANIZATION

BRAZZAVILLE

MARCH 1973

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1 INTRODUCTION

1.1 Scope

This Seventh Report of the WHO Sectorial Study attempts to assess the quantity, quality and distribution of the groundwater resources of Kenya through the preparation of hydrogeological maps utilizing borehole data.

The Terms of Reference of the four-month assignment for the Hydrogeologist included:

i) analysis of available data and preparation of groundwater maps, indicating the level of the groundwater table and the discharge;

ii) make recommendations on future groundwater investigations and development.

The Report is based on data on some 4 100 boreholes on which records are available within the Water Department within the Ministry of Agriculture. In addition to the borehole data available literature on geology and hydrogeology has formed an input to the Report.

1.2 Organization of the Report

The Introduction, Summary and Recommendations are presented in Sections 1, 2 and 3 respectively.

The general environmental setting and factors relevant to hydrogeology are presented in Section 4. General theoretical considerations are discussed in Section 5. Present resources involved on groundwater development are discussed in Section 6. The method of investigation is described in Section 7 and interpretation of results is presented in Section 8.

1.3 Acknowledgement

During the course of the study, extensive use was made of the existing literature on the geology and hydrogeology of Kenya. Every attempt has been made to acknowledge this in relevant portions of the Report and any error of omission is regretted.

Several discussions and interviews were held with Government officials, individuals and corporate Bodies; receptions in all cases were cordial and discussions were fruitful. As it is impossible to list all these individually, their assistance is gratefully acknowledged.

The different Sections of the Water Department were very helpful in rendering technical assistance and statistical information. In this regard, particular mention must be made of the Hydrogeology Section and the Drawing Office, without whose active support this work would not have been possible.

2 SUMMARY

The time available within this Project for the study of the groundwater resources of Kenya was very limited and did not permit full utilization of data available. The Report aims at giving a very general picture of quantity, quality and distribution of groundwater in the country and indicating what work should be undertaken in the future to improve the knowledge of Kenya's groundwater resources.

Kenya is a country of wide contrasts and this also applies to its geology and hydrogeology. Regional maps of hydrogeological parameters can only be indicative and serve as a guide for the planners.

In co-operation with the Statistics Division of the Ministry of Finance and Planning, the Water Department has established a computerized data bank on borehole data. The computer work was finalized during the course of this study with assistance from the University of Nairobi and has been the most valuable input to the study. The data bank will serve as a most useful tool in future analysis of groundwater data and in siting of boreholes. Computer print-outs with data on some 4 000 boreholes are now available to the Water Department. Information on location, depth, yield and rock type, is indicated for each borehole. Information on water quality and draw down is given where the data is available. The data is presented in three different formats, sorted on:

i) borehole number

ii) longitudes

iii) latitudes

The findings of the study are summarized as follows:

Evidence is herein presented to show the existence of a wide belt of shallow aquifers in the Quaternary sediments of Eastern Kenya. In most parts of Central Kenya, stretching from south-west and south-east and narrowing to the north-east, the depth to the first major aquifer is of the order of 50-150 metres. In the north-western parts of the country adjoining Lake Rudolf, the aquifers are also relatively shallow, - about 50 metres.

Most areas covered by the Quaternary and Basement Complex Systems are typified by unconfined aquifers, whereas groundwater in the older sediments and the volcanic areas are typically confined.

Although yield data are of limited reliability, the expected yield map is simple and appears to be strongly dependant on geology. Thus low yields are recorded for the Basement Complex areas and the highest figures occur in the Quaternary sediments in the east.

The quality of groundwater in most parts of Kenya is generally satisfactory for most purposes. The occurrence of saline water is a problem in the eastern areas (Wajir, Garissa, etc) but the occurrence of good quality waters in shallow wells and boreholes in the east is positive evidence that fresh water abounds in the shallow zones of this area. Inasmuch as fresh water floats over saline waters in many parts of this area, every drilling and abstraction should be closely watched to prevent irreversible damage to the aquifers through salt water contamination.

The high concentration of fluoride in certain areas may be due to the mixing of waters from different aquifers. Judicious sampling and analysis of waters from different major aquifers, should reveal which waters are unsuitable and hence sealed off. Defluoridation may be necessary in certain cases to reduce the fluoride content of such waters to acceptable levels.

The groundwater resources potential of Kenya appears promising but considerable more investigations are required before the resources can be mapped. There is an urgent need to update the existing data and acquire additional data for a more dependable assessment. Until this is done, the results presented herein are tentative and should be used only as a guide to future groundwater development and management.

3 RECOMMENDATIONS

3.1 Introduction

Water resources planning, development and management activities are carried out by the Water Department of the Ministry of Agriculture. The Hydrogeology Section is one of the many Sections of this Department.

Although over 4 000 boreholes have been drilled in Kenya, considerable information is still needed to fully assess the groundwater potentiality of the country. The recommendations below are aimed at increasing the knowledge of the groundwater resources for more effective utilization in the future.

3.2 The Logging of Boreholes should be Improved through Closer Supervision by Geologists on Site

Logging of boreholes is today carried out at WD Headquarters by Geologists, based on field samples and reports from the drillers. The samples are sometimes submitted late and not taken and handled properly.

Weekly or fortnightly supervisory visits to drilling sites by WD Geologists would improve the reliability of logging.

3.3 Proper Pump Testing should be Carried Out to Determine Hydrogeological Parameters Relevant for Assessing the Groundwater Resources

Pump tests carried out are not always properly done and are, in the case of high yielding boreholes, tests of the capacity of the pumps used rather than the maximum yield of the boreholes.

It is recommended that the standard pump testing forms should be made better use of and be made available to WD staff concerned.

3.4 A Network of Observation Boreholes should be Established

Except for the Nairobi conservation area and the Kaputei area of Kajiado district, there are no observation boreholes in the country.

Observation boreholes are necessary in order to establish the recharge to groundwater from precipitation. There are plans within WD to establish a network of observation boreholes. This is strongly supported by the Study. Observation boreholes should preferably be located in the vicinity of meteorological stations.

3.5 Chemical Analyses should be Carried Out for each Major Aquifer struck during Drilling

A water sample from a completed borehole may reveal the presence of undesirable properties (e.g. high fluoride content). Often, this is because the sample is a mixture of water from several aquifers. If each major aquifer is tested, where practical, it could be possible to seal off the aquifer with the non-desirable properties.

The borehole should be resampled after a period of use as some quantities could change after a period of pumping.

3.6 New Methods for Siting of Boreholes should be Tested

The most commonly used method today for siting of boreholes is by the geo-electric resistivity method. This method has proven to be rather inaccurate in volcanic areas. It is recommended that seismic and gravimetric methods should be tested, especially in volcanic areas. These methods should also be used to site boreholes in basement complex areas in order to determine thickness of weathered zones, faults, joints and crystalline intrusions.

3.7 Aerial Photography for Assessment of Groundwater Resources in Areas where no Borehole Data is Available should be tried

In many parts of the world use has been made of aerial photography for interpretation of groundwater availability. In areas where no borehole data is available, this method should be tested.

3.8 A Detailed Groundwater Investigation on the Lamu Island should be Carried Out

The Lamu Island is dependant on shallow wells for its water supply. The water needs are rapidly increasing because of growth of tourist industry. The fresh water is floating on the saline water.

In order to see if the available resources can support the installation of additional wells, it is recommended that a detailed study be carried out to determine if and where other wells could be dug and to establish steps required for prevention of pollution of the groundwater. Until such a study is carried out, the recommended maximum depths (Selby, 1969) should be strictly enforced.

3.9 A System should be Established for Updating of the Computer Data Bank on Boreholes

It is essential that the computer data bank on boreholes which has been developed, is updated. Data from new boreholes and monitored data from existing boreholes should be entered in the system. Updating of the data bank once a year is probably sufficient.

3.10 The Maps showing Expected Yield and Expected Depth to the Static Water Level are very tentative and more work should be Carried Out on these Maps

Because of the very limited time available for this study the borehole data bank was not fully utilized when these maps were produced.

It is recommended that these maps are improved in connection with the planned Master Water Plan Project.

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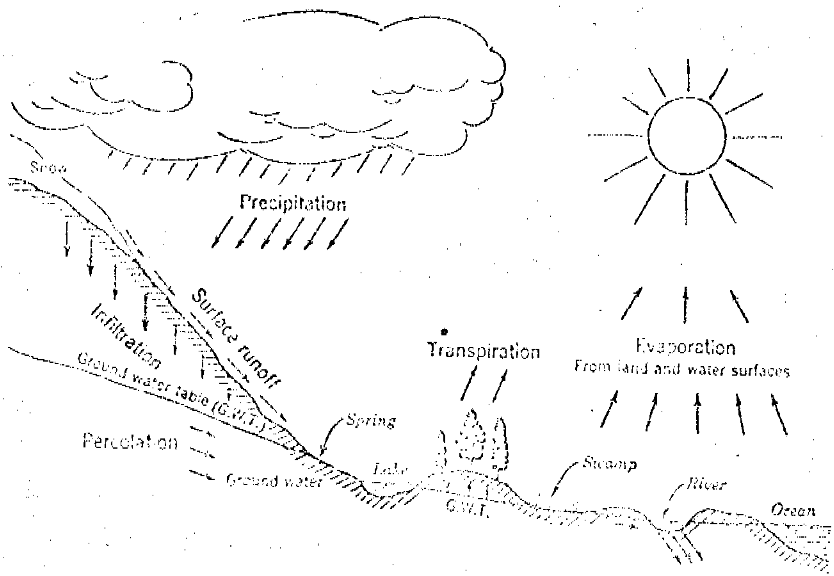
FIGURE 4.1

HYDROLOGIC CYCLE



WATER BALANCE EQUATION

$R_G = P - E - R_S \pm \Delta M$

R_G = Groundwater Storage

P = Precipitation

E = Evapotranspiration (Evaporation plus Transpiration from Plants)

R_S = Surface Runoff

ΔM = Change in Storage

4 ENVIRONMENTAL SETTING

4.1 Hydrologic Cycle (see also Figure 4.1)

The whole concept of groundwater storage is embodied in the hydrologic cycle which describes the complex global water movement from the time it falls as precipitation (rain, snow, mist, dew, etc) until it is returned to the atmosphere (by evaporation, evapotranspiration, sublimation, etc) for future precipitation. In this cycle, which describes the total global water balance, the components are many and varied (run-off, surface storage, formation of glaciers, infiltration to groundwater storage) but the portion of immediate interest in this Report is groundwater storage.

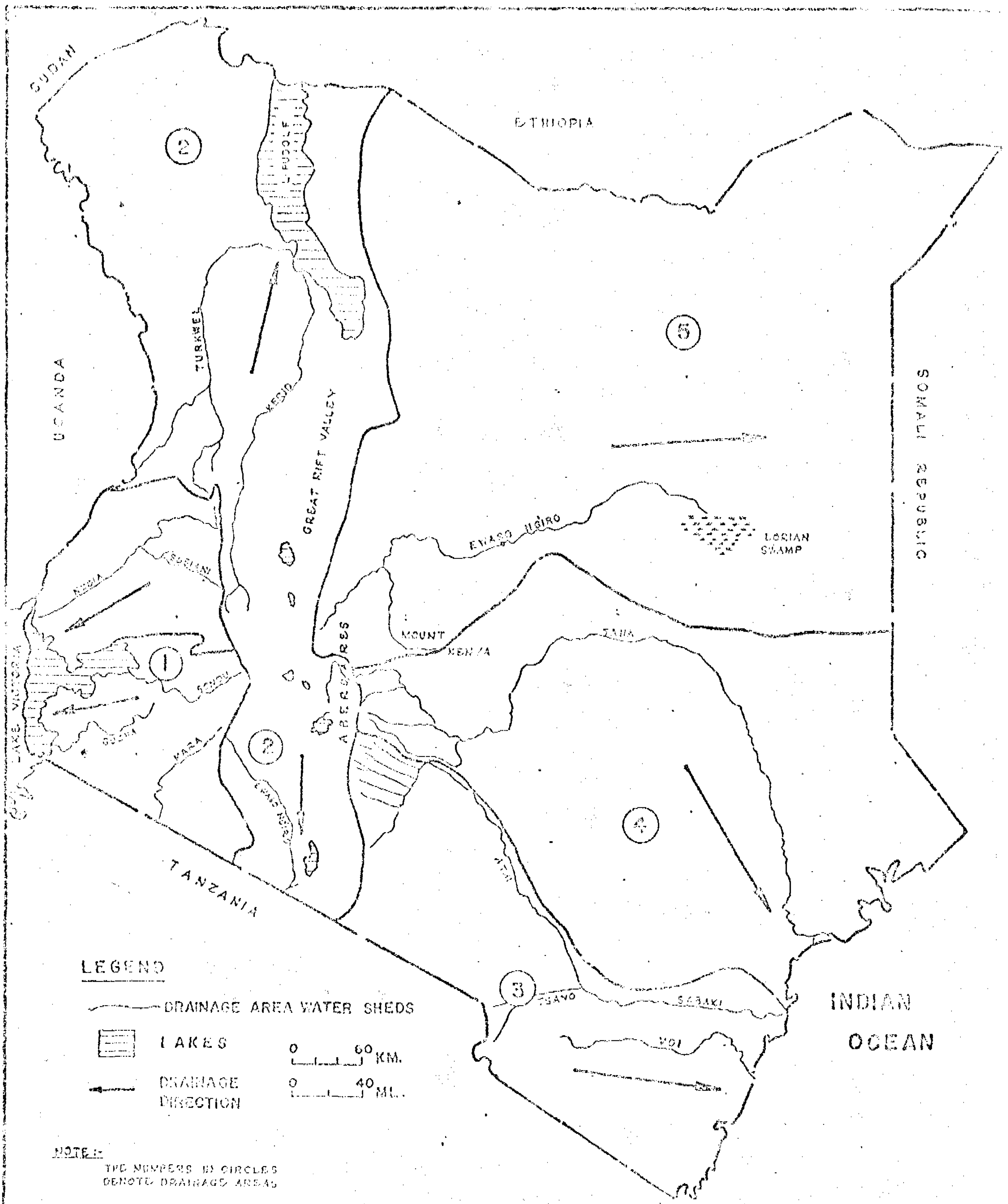
The volume and mode of groundwater storage is a function of several environmental factors. It is strongly dependant on the volume of precipitation (both intensity and distribution) and on the rate of infiltration also depends on the nature of the surface (geology, soils physiography, drainage). The volume that is lost by evapotranspiration on the other hand depends on such factors as vegetation, temperature and relative humidity. Hence an assessment of groundwater resources of an area must of necessity assess the relative significance of each of these parameters.

4.2 Location

The Republic of Kenya, covering an area of about 580 000 sq km, about 98 per cent of which is land, is a country of tremendous topographical diversity, extending from latitudes 4.3° South to 4.5° North and from longitudes 34° East to 41.9° East. It has a common border with Tanzania to the south and with Uganda to the west. In the north it is bounded by Ethiopia and Sudan farther to the north-west. The Republic of Somalia occurs in the east, whereas the Indian Ocean occurs in the south-east.

4.3 Physiography

The topography of Kenya ranges from glaciated and snow-covered mountains to a true desert (Chalbi Desert) and from old peneplains to volcanic and tectonic landscapes. The landscape, with a variation of 5 200 m (Batian Peak of Mt Kenya) is dominated by plateaux conveying the impression of extensive upland plains.



SOURCE:- NATIONAL ATLAS OF KENYA 1970.

WHO/KENYA - 3202

SURFACE DRAINAGE

FIGURE 4.2

The country can be divided into six physiographic provinces:

The Nyanza Low Plateau;

The Central Highlands bisected by the Great Rift Valley;

The Northern Plainlands;

The Foreland Plateau and

The Coastal Plains[1].

These topographic features have resulted from tectonic disturbance (epeirogenic and volcanic) and a series of long periods of subaerial erosion and deposition.

An important consequence of faulting is the Rift Valley System - a spectacular topographic feature with vertical displacements of up to 3 000 m in the Central Highlands. The mechanism for the formation of this system is still a matter of controversy but it appears that they originated from uplift and faulting by tensional forces at the crest of an up-arched dome.

4.4 Drainage (see also Figure 4.2)

The Great Rift Valley is the dominant determinant of the drainage pattern of Kenya, although local details of relief are responsible for variations in the regional drainage pattern. Thus, on a regional scale, we can distinguish five drainage areas.

Numerous rivers drain Area I west of the Rift Valley into Lake Victoria and Lake Kioga in Uganda. In the Rift Valley itself (Area 2) internal drainage into Lake Rudolf and Lake Natron predominates. The southern part of the country east of the Rift Valley is drained by the Athi River and its tributaries (Area 3) which discharge into the Indian Ocean. The eastern slopes of the Aberdare Range as well as the southern slopes of Mt Kenya and the Nyambene Range (Area 4) are drained by the Tana River (the largest river in Kenya) which also empties into the Indian Ocean. The northern slopes of these highlands are also drained by the Ewaso Ng'iro which normally disappears in the Lorian Swamp, except in rather wet years when it may flow into Somalia[1].

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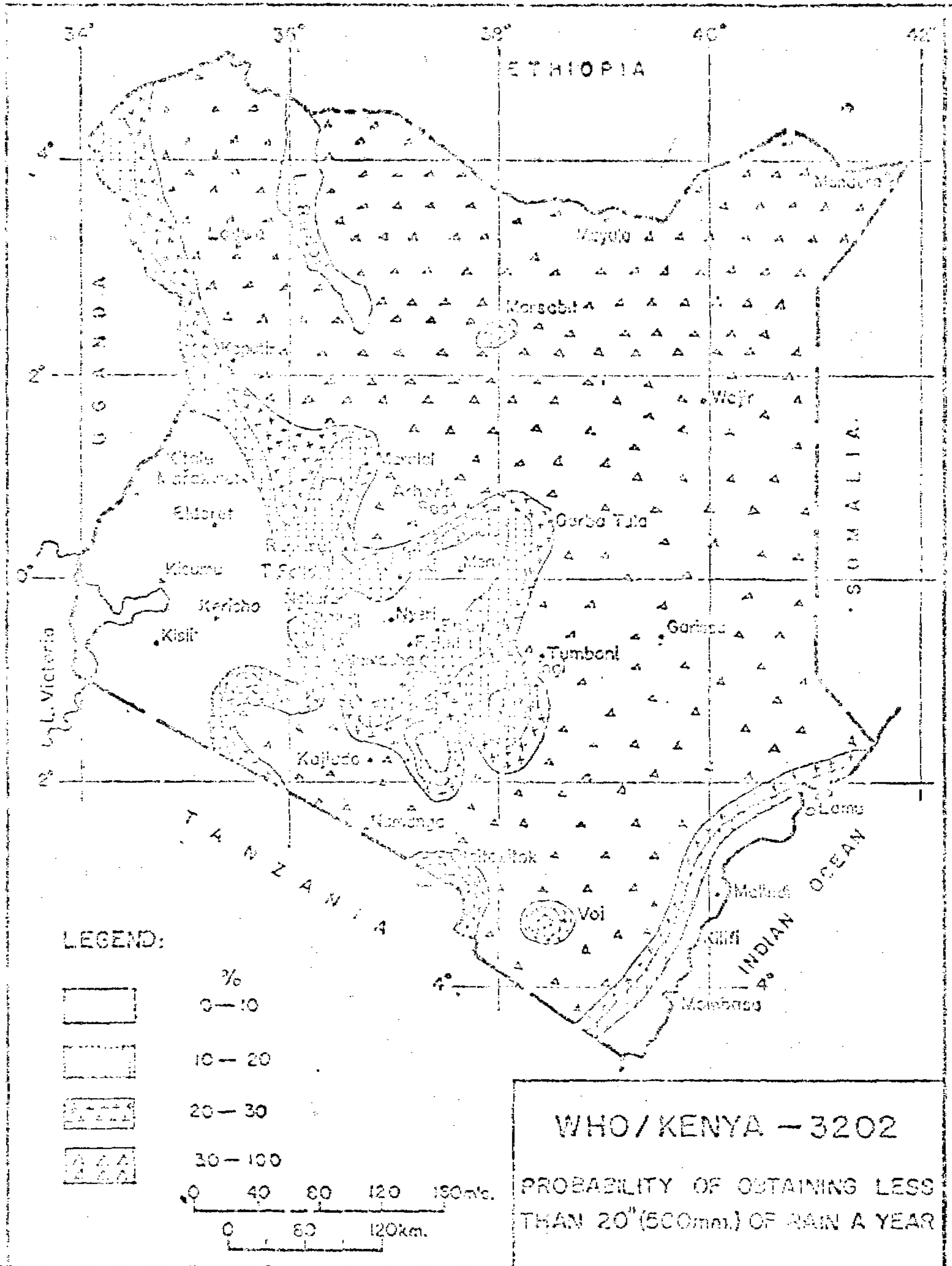
[1]National Atlas of Kenya. Survey of Kenya 1970



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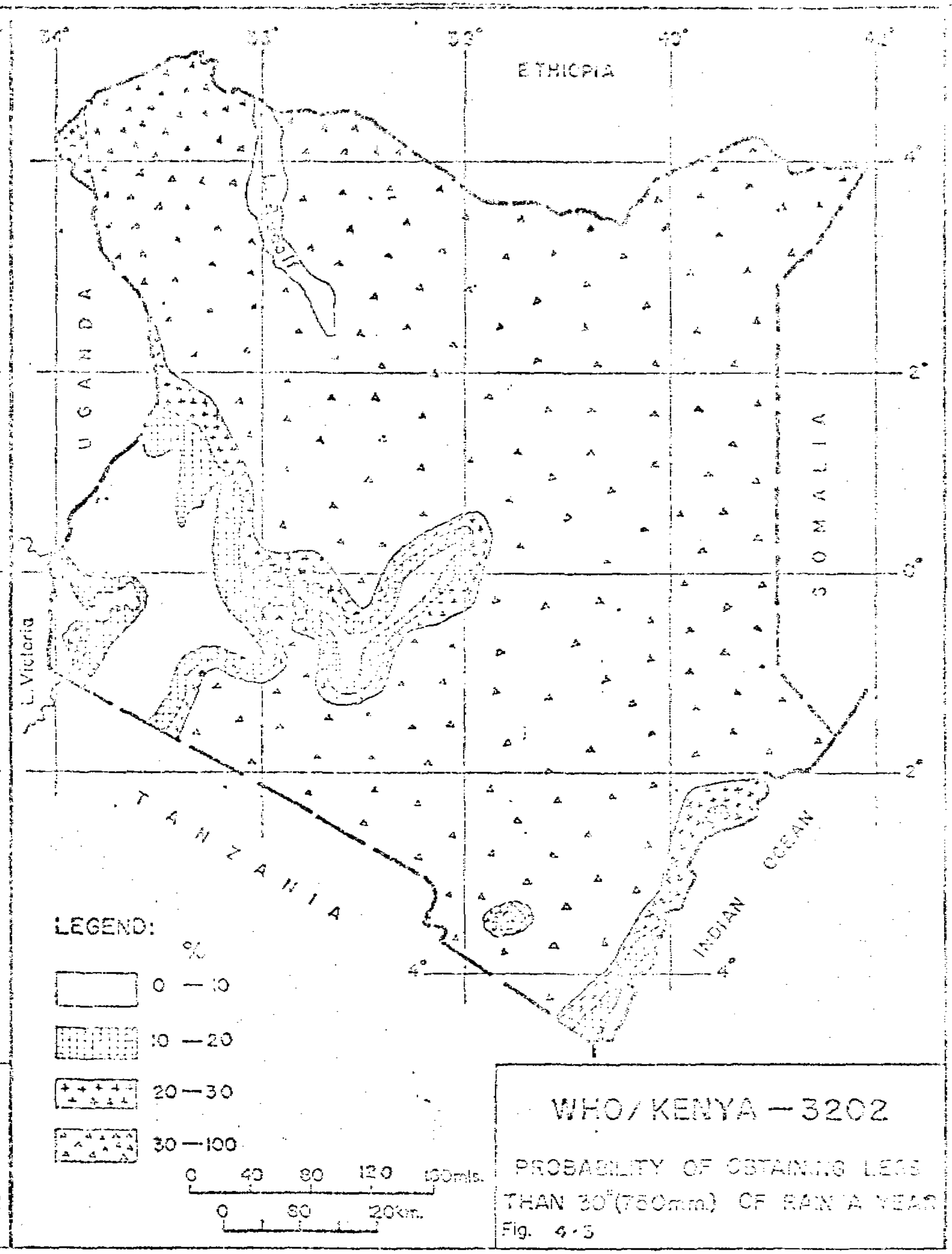
PROBABILITY OF OBTAINING LESS THAN 20" (500 mm.) OF RAIN A YEAR



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PROBABILITY OF OBTAINING LESS THAN 30" (750 mm.) OF RAIN A YEAR

Fig. 4·3

Consequent parallel streams drain the Aberdare and Mau dip slopes as well as the Wajir-Duruma Low Belt between Galana and Tana Rivers. The volcanic cones are washed by minor radial streams whereas fault-guided streams typify the Grid-faulted parts of the Rift Valley.

4.5 Climate

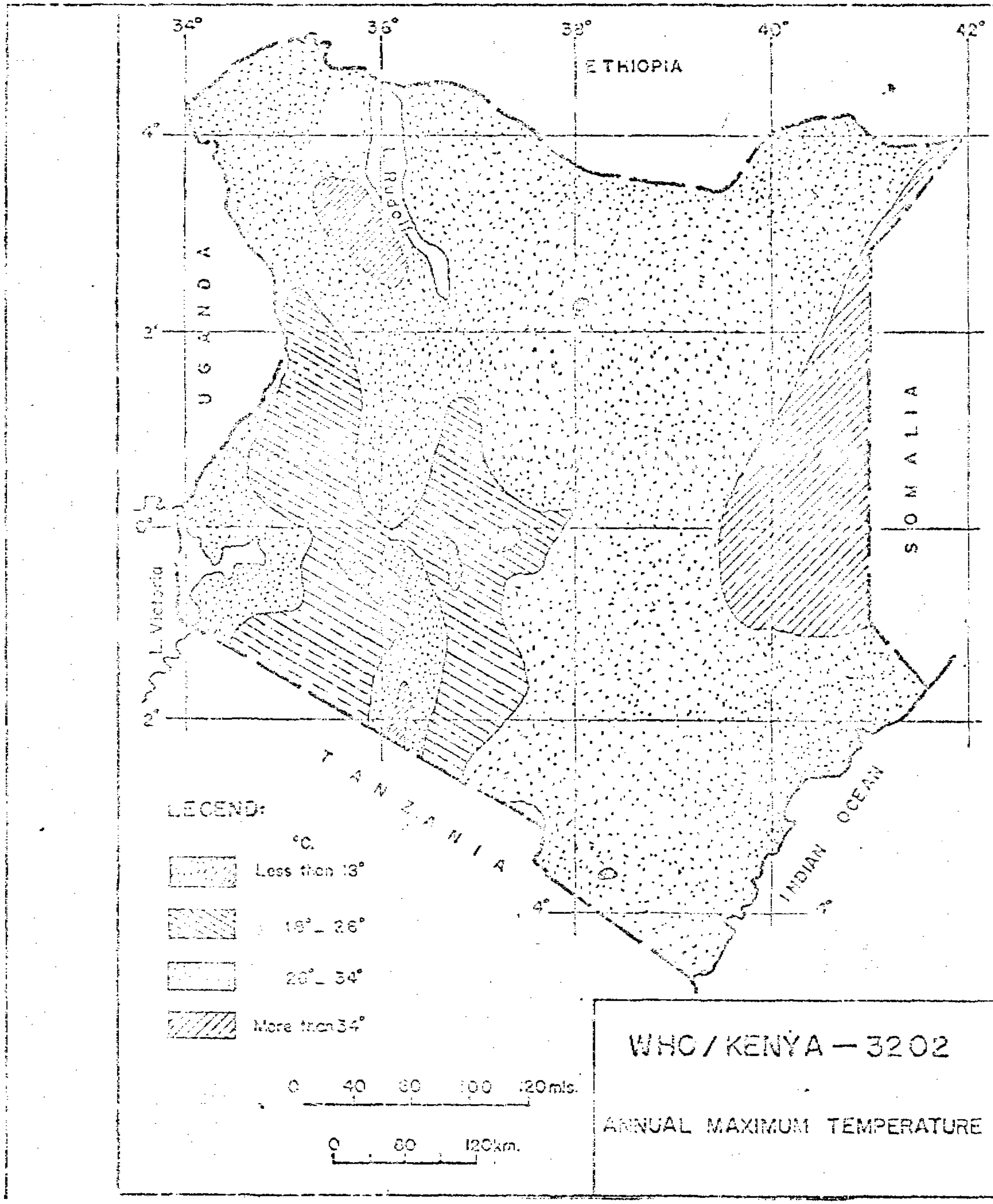
On account of the geographical location of Kenya, the sun at noon is always high and the average sunshine duration is 7 hours per day or 2 500 hours per annum, with a remarkable total of 3 000 hours per annum in the northern areas.

Wind speeds at ground level are low, averaging 160 km/day and reaching 350 km/day at high elevations. Gusts associated with thunder-storms (11 km/hr) occur around Lake Victoria. Humidity is high, particularly between May and October. The skies are generally clear over the lowlands but the mountain tops may be covered by clouds for long periods. The monsoon changes in wind direction, often bringing excellent visibility, periodically allowing Mt Kilimanjaro to be seen from Nairobi, 210 km away. Hail-storms occur about three times a year and snow is known to fall above 4 750 m on Mt Kenya, Mt Elgon and the Aberdares.

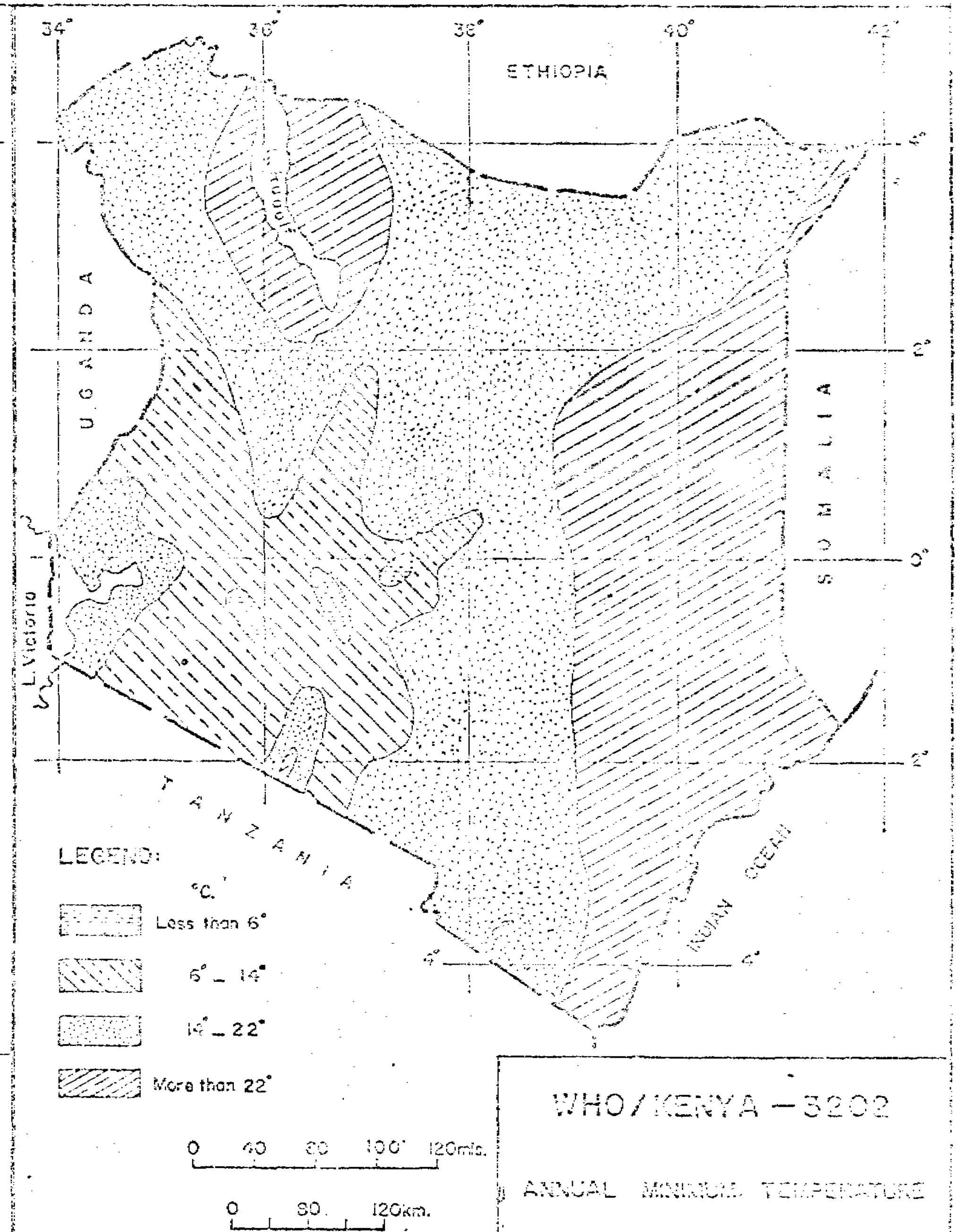
4.5.1 Rainfall (see also Figure 4.3 and Figure A1, Appendix A)

The world average annual rainfall over land is 650 mm; the average for Kenya is 380 mm. However, much of Kenya receives less rainfall; only 15 per cent of the country has an average rainfall in excess of 750 mm. Annual rainfall of over 2 500 mm has been recorded on Mt Kenya, 1 100 mm in Mombasa and 1 500 mm around Lake Victoria. The general pattern of distribution is shown in Figure 4.3. In Figure A1, Appendix A, a map is presented showing mean annual rainfall.

Rainfall is strongly seasonal although there are no absolutely dry months and rain may fall rather unexpectedly anywhere in Kenya. Such seasonal variations are, however, strongest in the dry lowlands to the north and east.



ETHIOPIA
UGANDA
SOMALIA
TANZANIA
INDIAN OCEAN
L. Rudolf
L. Victoria
LEGEND:
°C.
Less than 13°
13°– 26°
26°– 34°
More than 34°
0 40 80 100 120 mls.
0 80 120 km.
WHO/KENYA – 3202
ANNUAL MAXIMUM TEMPERATURE



ETHIOPIA
UGANDA
SOMALIA
TANZANIA
INDIAN OCEAN
L. Rudolf
L. Victoria
LEGEND:
°C.
Less than 6°
6°– 14°
14°– 22°
More than 22°
0 40 80 100 120 mls.
0 80 120 km.
WHO/KENYA – 3202
ANNUAL MINIMUM TEMPERATURE

Fig. 4·4

4.5.2 Temperature (see also Figure 4.4)

The Republic of Kenya is a conspicuous example of the modification of temperature by altitude. The maximum temperatures are recorded in the low-lying semi-arid areas (38^{o}) where the minimum night temperatures are well above 20^{o}. The afternoon breeze keeps the temperatures down around Lake Victoria, where the October-March maximum afternoon temperature is about 32^{o}C. It is coldest on mountain tops where night frosts occur above 3 000 m and permanent snow cap above 5 000 m (Mt Kenya). The diurnal range in temperature (daily maximum minus daily minimum) reaches 16^{o} C in the Rift Valley area and 10-16^{o}C in the central and southern highlands and plateaux. On the coast it is 5-8^{o}C where the maximum temperature is of the order of 32^{o}C in January-March and during the coolest months it is 27^{o}C [1].

4.5.3 Evapotranspiration (see also Figure B1 in Appendix B)

Evaporation and transpiration are the only physical processes by which water is transformed into vapour. All water that falls on or is discharged into the ocean, as well as all that enters subsurface reservoirs, if not fixed by chemical reaction, is finally returned to the atmosphere by these processes. Inasmuch as it is difficult to accurately determine the two components independently of each other, the two are often estimated together as evapotranspiration.

A preliminary regional survey of the potential of evaporation reported by Woodhead[2] in 1968 shows the degree of variability of this factor in different areas of Kenya. The highest annual figure is recorded at Magadi (4 060 mm) in the lower end of the Rift Valley. In the arid north, the figure varies between 2 790 mm and 4 060 mm to 1 650-2 410 mm at the coast where humidity is high.

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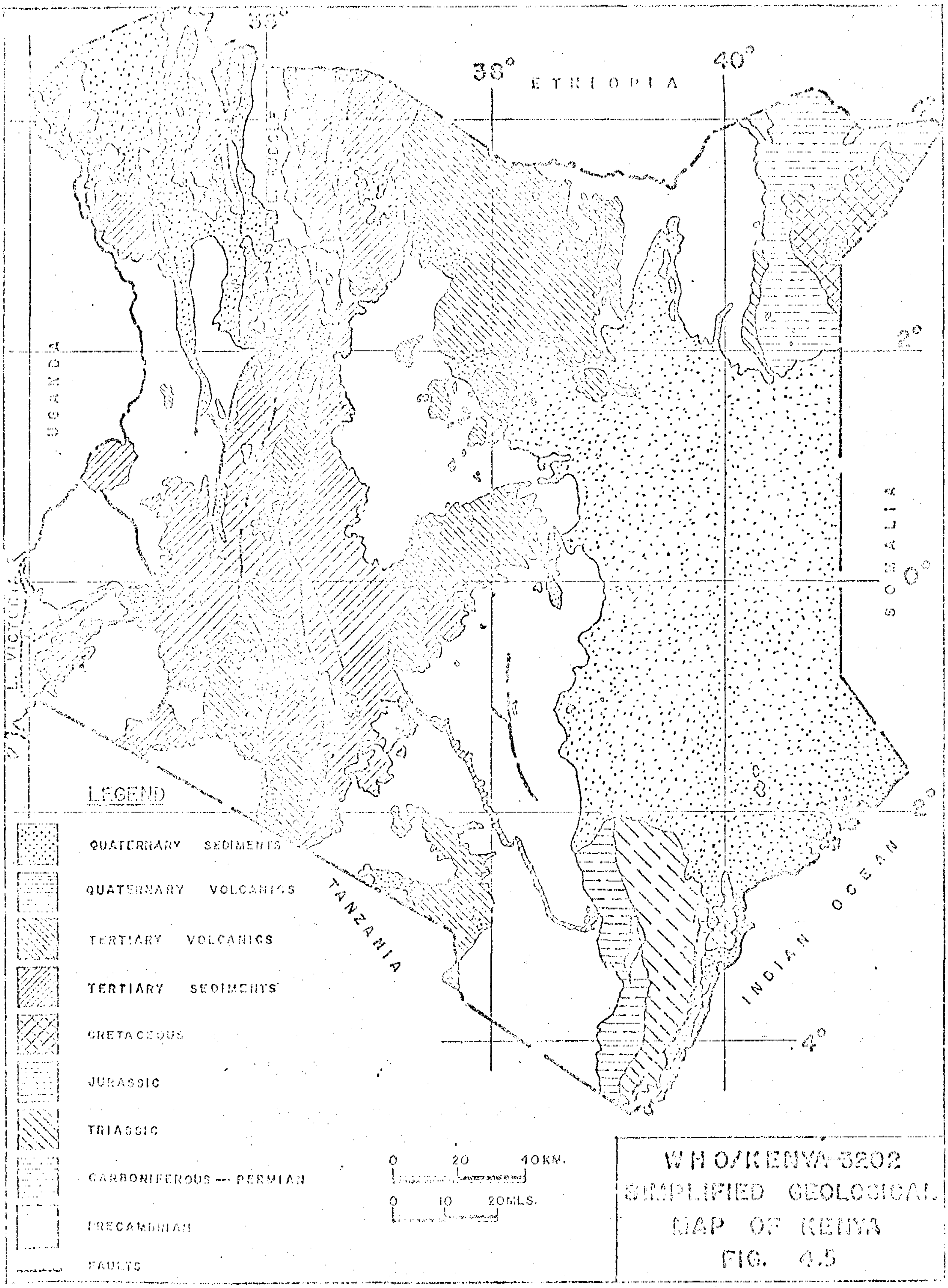
[1] National Kenya Atlas, Survey of Kenya 1970

[2] Woodhead, T. 1968, Preliminary Regional Survey of Potential Evaporation



WHO/KENYA-3202
SIMPLIFIED GEOLOGICAL MAP OF KENYA
FIG. 4.5

Figure B1 shows that areas of low precipitation are coincident with those of high Penman (E_o) potential evaporation. The effect of altitude is not altogether clear although there appears to be a general trend in which a decrease of about 100 mm in evaporation accompanies a rise of 700 m in altitude.

4.6 Vegetation

The ecological situation as well as prolonged human use in Kenya (grazing, burning, selective cutting and shifting cultivation) permits many vegetation types. On the whole, the vegetation can be classified into six groups; Forest, woodland, bushland, bushed and wooded grasslands, permanent swamps and barren land.

These basic vegetation types occur superimposed or in mosaic. The forests and woodlands occur in the wetter areas in the west and in the coastal areas to the east. The north, north-east and a considerable portion of the central parts, are covered by grasslands.

4.7 Geology (see also Figure 4.5)

The geology of Kenya is complex and all the major rock types - igneous, metamorphic and sedimentary - are represented in the geologic column. The areal distribution of these rock types is presented in Figure 4.5 and the geological stratigraphy is presented in Table C1 in Appendix C.

The sedimentary rocks occur predominantly in eastern and north-western parts. They are composed of clays, shales, sands, sandstones, limestones as well as other less important lithologies. They range in age from Carboniferous to Recent.

Volcanic activities started in mid-Tertiary and continued to the Recent, extruding a whole range of rock types which are today significant in the groundwater storage of Kenya. These volcanic rocks occur mostly in central parts of Kenya, where they are associated with the faulted zones. This is an indication of a cause-and-effect relationship.

KENYA

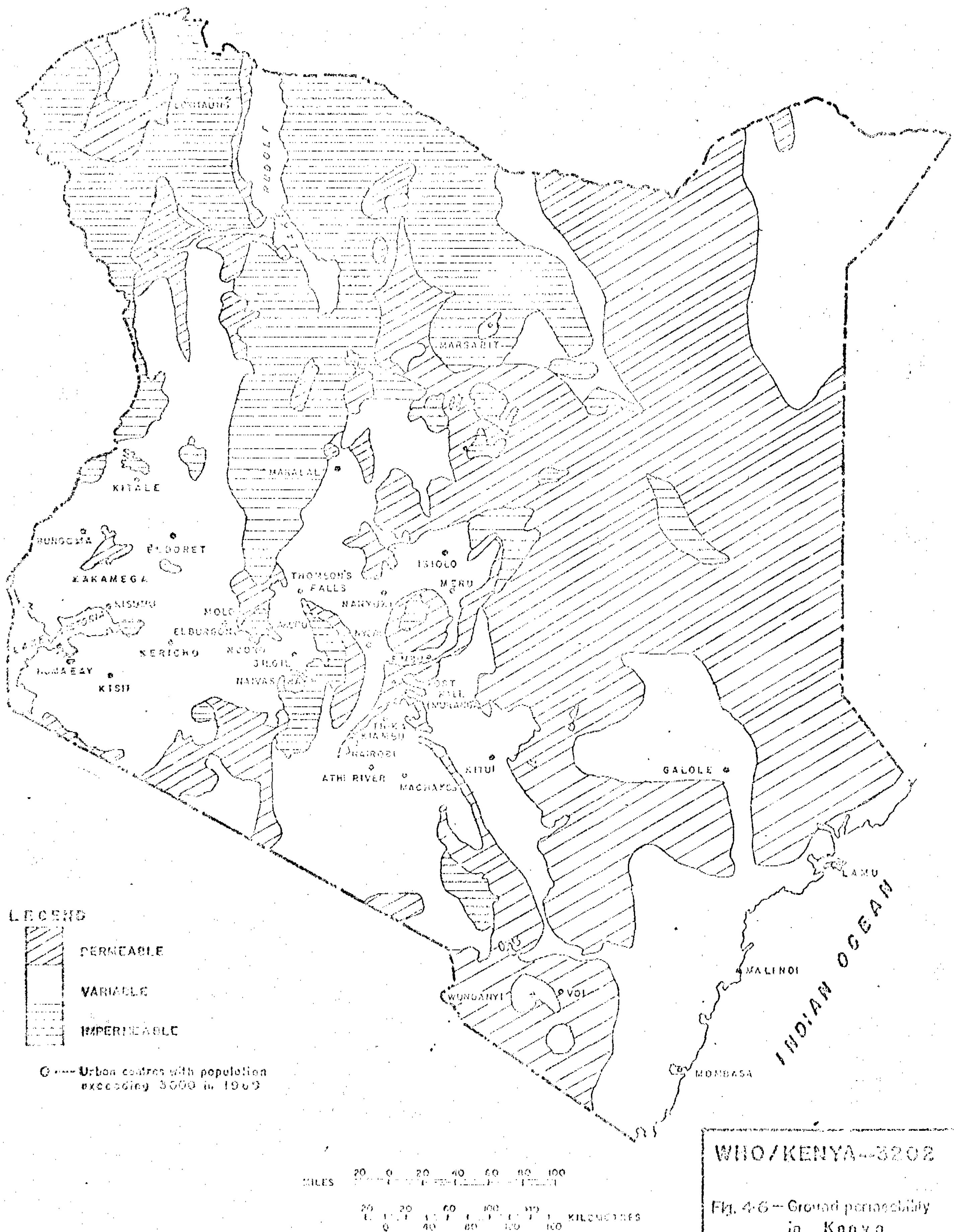


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Fig. 4-6 — Ground permeability in Kenya

The hard, crystalline igneous and metamorphic rocks of the Basement Complex occur in different parts of Kenya (Figure 4.5). Generally such rocks have limited porosity and are hence not good aquifers except on a local scale, where secondary processes have modified their primary water-bearing properties.

A more detailed, simplified geological description is presented in Appendix D.

4.8 Surface Cover (See also Figure 4.6)

Inasmuch as the rate and volume of recharge depends on the nature of surface cover, Figure 4.6 has been derived from the soil map of Kenya[1]. Three "permeability categories" are therefore derived from information presented on the soil map.

When this soil map is studied with Figure 4.5, the effect of geology on the potential permeability becomes obvious. Thus the eastern parts covered by sedimentary rocks are rather permeable, whereas the least pervious areas are located in the volcanic belts.

A knowledge of the potential degree of permeability is important, not only in assessing the degree of groundwater recharge but also in planning the disposal of man-made domestic industrial and agricultural wastes.

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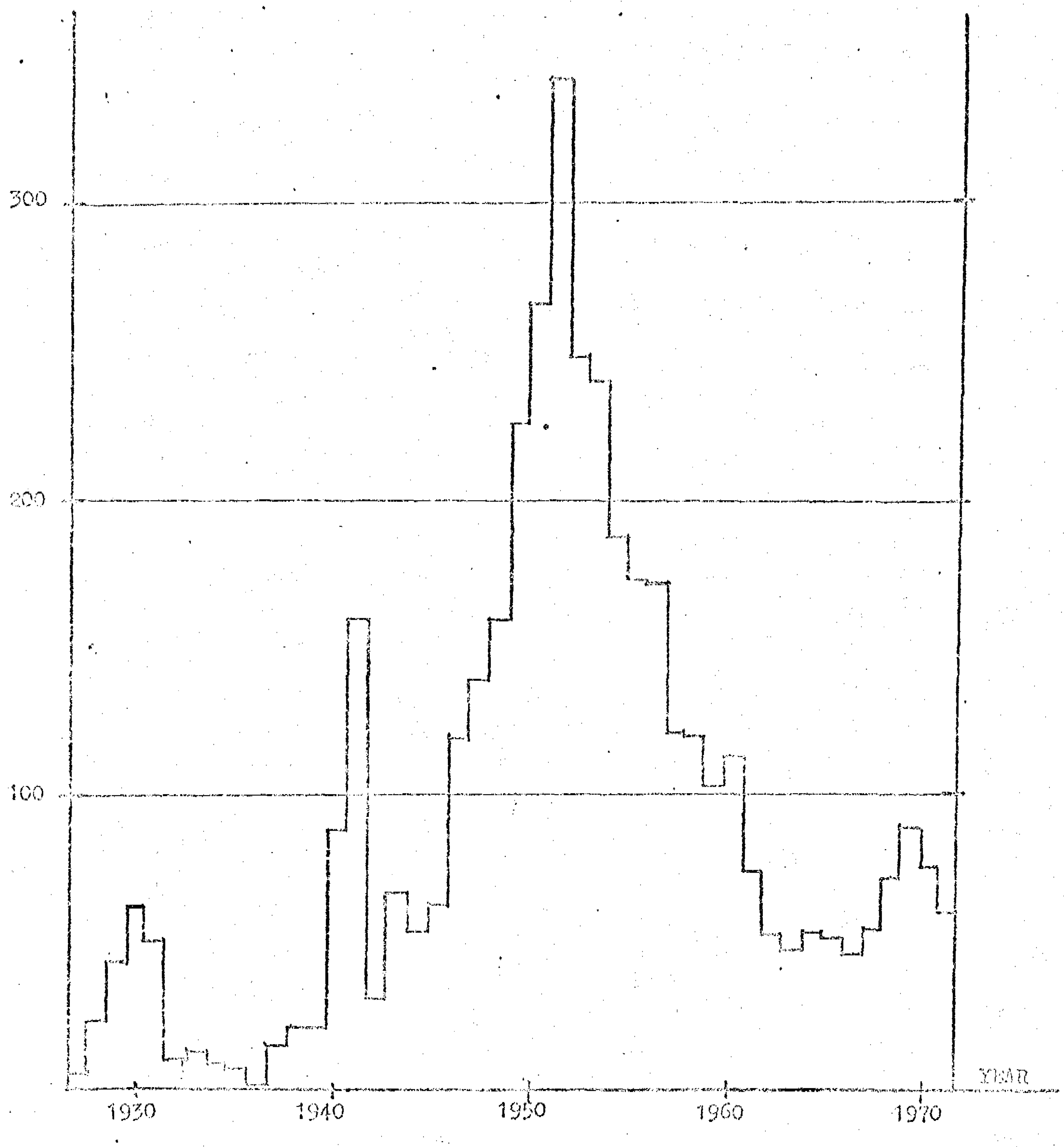
[1]National Atlas of Kenya, Survey of Kenya 1970

NUMBER OF BOREHOLES DRILLED PER ANNUM



5 BASIC DATA ON GROUNDWATER IN KENYA

Exploration and drilling for groundwater began in Kenya in the late 1920's. The first hole was drilled in 1927 by the Public Works Department of the then Kenya Colony. By 1934, 190 such boreholes had been drilled, all prefixed by "P" (e.g. P.101 for borehole No. 101). The aggregate footage was of the order of 50 000.

During the Second World War, 133 boreholes were drilled, all prefixed by "SA".

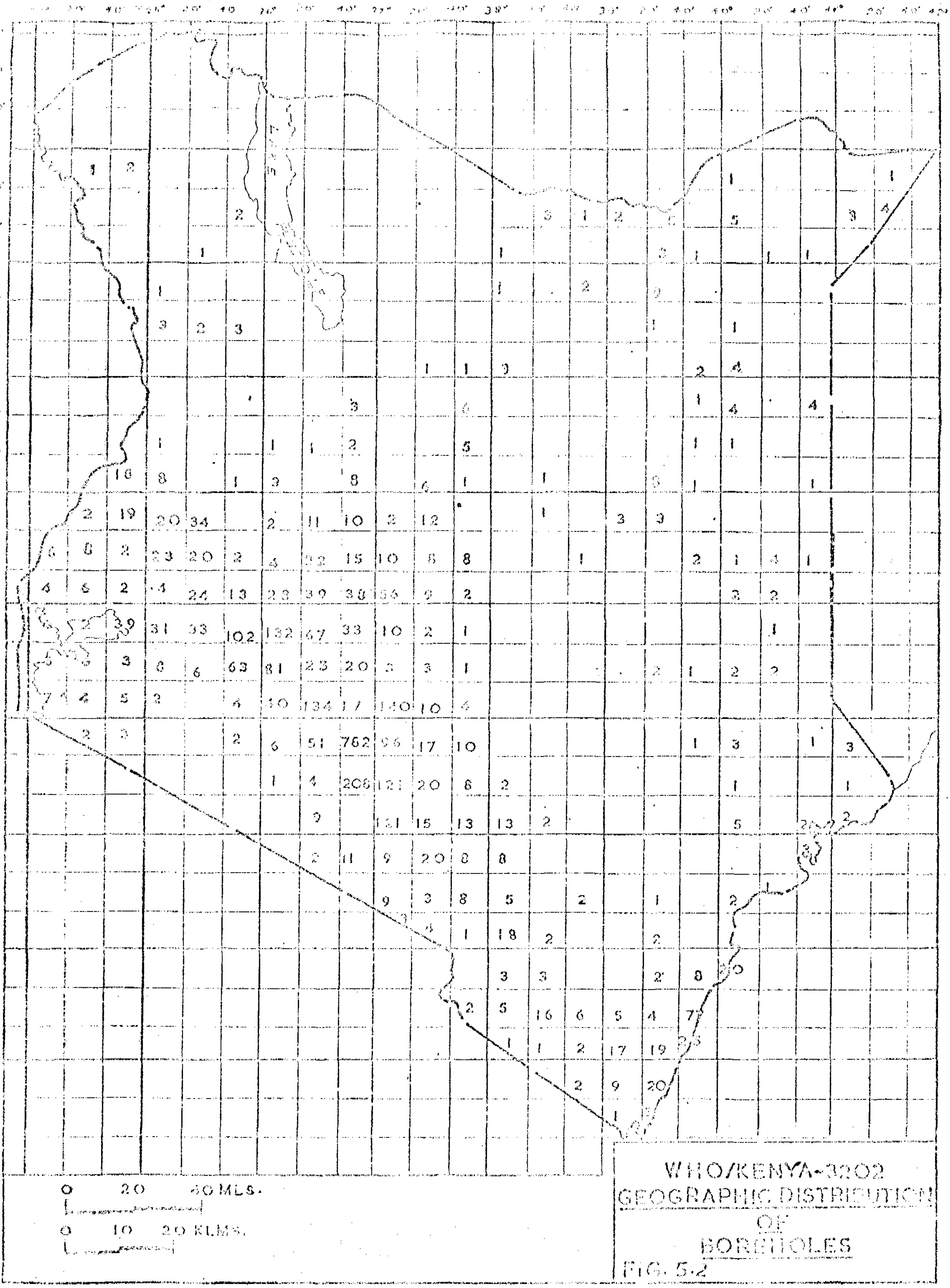
A third set of boreholes was started in 1938 and has continued to date, prefixed by "C" and numbered serially. By the last count, 3 838 boreholes had been drilled in the "C" series. Figure 5.1 shows the number of boreholes drilled per annum since 1927.

Boreholes may be drilled by the local or central Government as well as by individuals and corporate bodies. Borehole drilling is, in most cases, preceded by the completion of an application form (WAB-245 B) which, when approved by the Water Department of the Ministry of Agriculture, entitles the applicant to proceed with the drilling. The Water Department may withhold approval on technical grounds. When a borehole has been drilled it is assigned a serial number. Hence all boreholes that have been drilled in Kenya during the last forty-five years are listed and plotted on a base map and the records of most of them are filed with the Department.

It is not necessary to apply for a permit to dig a shallow well except when abstracting water from a conservation area within half a mile (0.8 km) of an existing borehole, or in the vicinity of a river. It is estimated that about 2 000 hand-dug wells tap shallow aquifers in Kenya.

The information on the 4 161 boreholes as well as that collected from some hand-dug wells and several geological investigations forms the bulk of the groundwater data for Kenya.

Figure 5.2 shows the geographical distribution of boreholes. The distribution follows the population density.



WHO/KENYA-3202
GEOGRAPHIC DISTRIBUTION
OF
BOREHOLES
FIG. 5.2

5.1 Borehole Statistics

The Water Act provides that certain data be submitted within one month of the completion of a borehole. The standard form (WAB. 28) demands information on location (by district), ownership, date of commencement and completion, diameter and depth of hole, length of casing left in the borehole, tested yield, water quality and borehole log. A separate form (WRG.3) is also completed in duplicate and filed with the Department after the water has been analysed by the Government Chemist. This form requests information on eight anions and eight cations, as well as on total hardness, carbonate hardness, non-carbonate hardness, biochemical oxygen demand and total dissolved solids.

5.2 Previous Investigations

Over 150 published and unpublished reports are available on the geology and hydrogeology of Kenya. Although considerable inferences on the hydrogeological setting can be gained from the purely geological reports, less than 30 per cent of these deal directly with hydrogeology.

Most of the hydrogeological reports turn out to be essentially geological reports. Such reports are limited to comparatively small areas of the country and make no attempt to relate such areas with adjacent areas. Hence the knowledge of the geological and hydrogeological setting of one area gives only little aid in predicting the expectations in unexplored surrounding country.

Significant reports are those by Bristow et al, 1964; McCall, 1957, 1967; Gevaerts; Pulfrey, 1960; Sykes, 1934 and Scott, 1953. These and several others were studied during the course of the study.

Therefore, it is important to note that considerable published information is available on the groundwater resources of Kenya.

However, as these are scattered, there is a need for a comphrensive synthesis and compilation.

The research unit of the Hydrogeology Section also carried out research in geophysical techniques, but in most cases the areas are limited and results not fully processed.

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6 RESOURCES ENGAGED ON DEVELOPMENT OF GROUNDWATER

6.1 Water Department, Ministry of Agriculture

The Hydrogeology Section of the Water Resources Branch of WD is responsible for siting of all boreholes in Kenya. The Section has a staff of eight Geologists.

Three percussion drilling rigs are operated by the Section. The annual production is about 10 boreholes with an average depth of 100 m.

The majority of the drilling work is carried out by contractors. There are eight licensed drilling contractors, all utilizing percussion rigs.

The contractors are competitive. It is recommended that WD continues to utilize drilling contractors for the majority of the borehole drilling.

The geologists of the Section site on an average 100 boreholes/year, including boreholes for farmers. Some 300 water samples for chemical analysis are taken per year by the Section. The samples are tested by the Government Chemist. Although results from the Government Chemist are reliable they are frequently delayed due to their heavy work load.

6.2 FAO Team on Range Water Development

In 1969, a livestock development project financed by IDA/SIDA was launched. About £ 1 million of the total cost of the Project will be spent on water development. The first phase, which is scheduled to take 5 years, includes development of range lands in the North Eastern Province and ranches in the Kajiado District in the Rift Valley Province and Taita District in the Coast Province.

An FAO team has carried out feasibility studies for the ranch areas to be developed, including groundwater investigations.

The team has also carried out feasibility studies for a second phase of the livestock development programme in the Isiolo and Marsabit Districts of the Eastern Province.

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The following reports have been issued by the FAO team:

Range Development in Kaputiei, 1970
(AGP:SF/KEN 11, Working Paper No. 1)

Range Development in Taita District, 1970
(AGP:SF/KEN 11, Working Paper No. 2)

Range Development in Isiolo District, 1971
(AGP:SF/KEN 11, Working Paper No. 3)

Range Development in Marsabit District, 1971
(AGP:SF/KEN 11, Working Paper No. 9)

6.3 USAID Team on Range Water Development

A USAID team is involved in the implementation of the range programme in the North Eastern Province.

A Hydrogeologist of the team has carried out extensive groundwater investigations in the Province and has sited boreholes along stock routes and in grazing areas.

Proposals for a second phase have been submitted to the Kenya Government.

The following reports have been issued by the team:

Development Plan and Feasibility Study on a Pilot Range Development Project, North Eastern Province, Kenya
(Unpublished) June 1970

Ground Water Exploration in North-Eastern Kenya
Dr W. V. Swarzenski and S. Wanyeki
(Unpublished) November 1972

6.4 UNDP Geothermal Project

A UNDP Project is currently carrying out a feasibility study for the development of geothermal power in the Rift Valley around Lakes Naivasha, Hannington and Elementaita. Extensive geological and hydrogeological investigations have been carried out to map the groundwater resources. Tests have been carried out over several months on an old borehole (39 mm) producing steam. The prospects seem good and a full scale test borehole (200 mm) will soon be drilled.

6.5 WHO Project on Groundwater and Sewerage for Greater Nairobi

The feasibility of augmenting the Nairobi water supply with groundwater is being studied by a WHO Project. A major problem is the high fluoride content in the groundwater in the Nairobi area. Possibilities of blending groundwater with surface water are being studied.

6.6 Research by EAAFRO

The East African Community has a research station at Muguga outside Nairobi where research on groundwater availability in East Africa is being carried out.

Studies with analogue computer are carried out to obtain an overall picture of the water balance and the groundwater recharge. The research is in an early stage and no results are yet available.

7 METHOD OF INVESTIGATION

7.1 Borehole Statistics

The Water Department of the Ministry of Agriculture maintains records of water boreholes drilled in Kenya. Their records date back to 1927. The retrieval system of the stored data has, until recently, been very cumbersome and the data has not, therefore, been fully utilized. The Water Department in co-operation with the Statistics Division of the Ministry of Finance and Planning, started in 1971 to systemize available borehole data for computer processing.

At the time the groundwater study of this Project started (April 1972) most of the data had been coded. The location of boreholes, that is, latitude and longitude for each borehole, had not yet been coded. A preliminary print out was available with the boreholes sorted according to borehole numbers; that is, in chronological order. The preliminary print outs were reviewed by the Project Hydrogeologist, who recommended some additional parameters to be included, namely: ground elevation and draw down.

Due to high workload, the computer programmers of the Statistics Division could not promise to have the computer print outs available before the departure of the Project Hydrogeologist. In order to save time it was decided to commission the computer work to the University of Nairobi. Results were promised within two weeks but serious delays were encountered. The computer print outs were eventually submitted by the end of July.

The borehole data was sorted out in three different ways:

i) by borehole number

ii) by longitude

iii) by latitude

Examples of the print outs are presented in Appendix E.

7.2 Coding of Borehole Data

The computer print outs give the following parameters:

1. Borehole Number
2. District
3. Longitude
4. Latitude
5. Depth of Borehole
6. Water Struck Level
7. Elevation
8. Water Rest Level
9. Elevation of Water Table
10. Tested Yield
11. Draw Down
12. Yield/Draw Down
13. Rock Category
14. Water Quality
15. Completion Date
16. Subsidy
17. Elevation of Water Table

The coding of these parameters is described in detail in Appendix E.

7.3 Processing of Data

In addition to the computer sorting of borehole data, some computer processing was carried out.

7.3.1 Water Table

The average elevation of the water table above mean sea level within each district was calculated. The result is presented in Appendix F.

7.3.2 Depth of Boreholes

The average depth of boreholes within the three major petrologic types of rock, igneous, sedimentary and metamorphic, was calculated.

The result is presented in Appendix G. As can be seen from the data, the standard deviation equals about half the average depth within each rock category, which means that the individual values are rather scattered.

7.3.3 Yield of Boreholes

The average yield of boreholes within the three major petrologic types of rock was calculated and is also presented in Appendix G. The standard deviation is of the same order as the average value which indicates that an analysis on this broad basis is not very significant. It is recommended that future analyses should be based on a narrower geographic distribution than was used in this study. Time did not permit further detailed computer analyses of the data.

7.3.4 Specific Capacity

The average specific capacity of boreholes within the three major petrologic types of rock was calculated and is presented in Appendix G. The standard deviation is about double the average value and could not, therefore, serve as an input to preparation of a specific capacity map.

7.4 Preparation of Maps

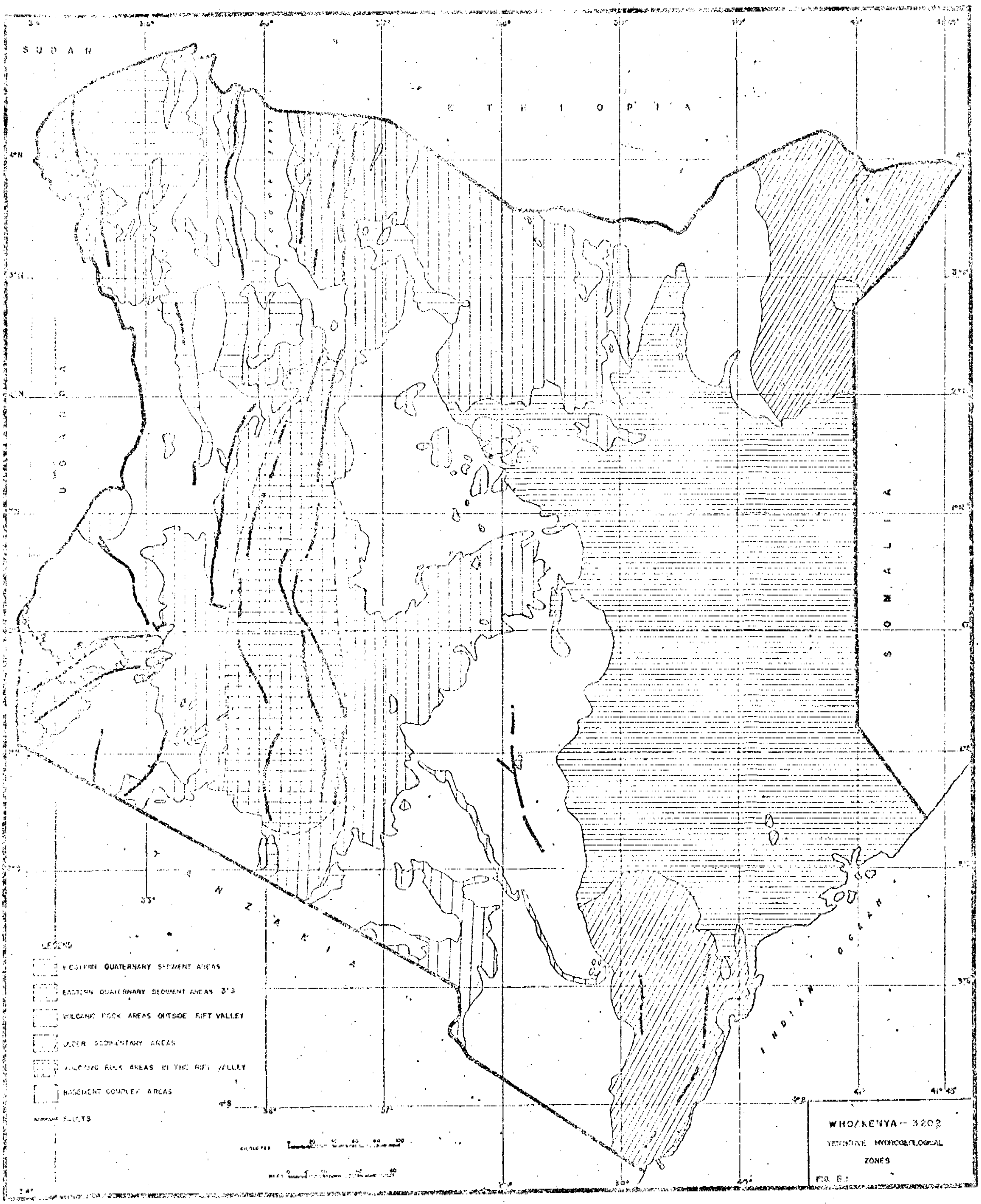
As pointed out under 7.3, the statistical analyses of borehole data by means of computer were not very extensive and not conclusive enough to serve as a major input to hydrogeological maps.

The maps presented in Section 8 were prepared through manual analyses of the borehole data.

Borehole locations were marked on a map in scale 1:1 000 000. In densely populated areas the borehole density is very high, only a few representative boreholes were marked. In less densely populated areas, all boreholes were marked on the map. The values from the computer print outs for depth, yield, etc were marked on this map. The contours on the maps for depth and yield were derived from this marked-up map.

7.5 Literature

A list of references is presented in Appendix M.


SUDAN
ETHIOPIA
SOMALIA
INDIAN OCEAN
LEGEND
QUATERNARY SEDIMENT AREAS
EASTERN QUATERNARY SEDIMENT AREAS 3°S
ROCK AREAS OUTSIDE RIFT VALLEY
AREAS
AREAS IN THE RIFT VALLEY
AREAS
WHO/KENYA
HYDROGEOLOGICAL
ZONES

8 INTERPRETATION OF DATA

8.1 General

The various parameters studied during the course of the study are presented in form of maps. Information derived from hand-dug wells tapping shallow aquifers has been used in the interpretation of the data but they have not been presented on any of the maps. The borehole data used are those collected at the time of drilling and no checks have been possible during this study nor is there any available information on their later history. Consequently it is uncertain how much groundwater conditions have since changed. For example, six of the boreholes visited in the coastal area had been abandoned although there was no record to that effect. As no account has been given on the static water level rises from rainfall and falls from abstraction, it has not been possible in this study to determine the groundwater balance.

An attempt has been made to divide the country into hydrogeological zones, see Figure 8.1 and also Section 8.4.

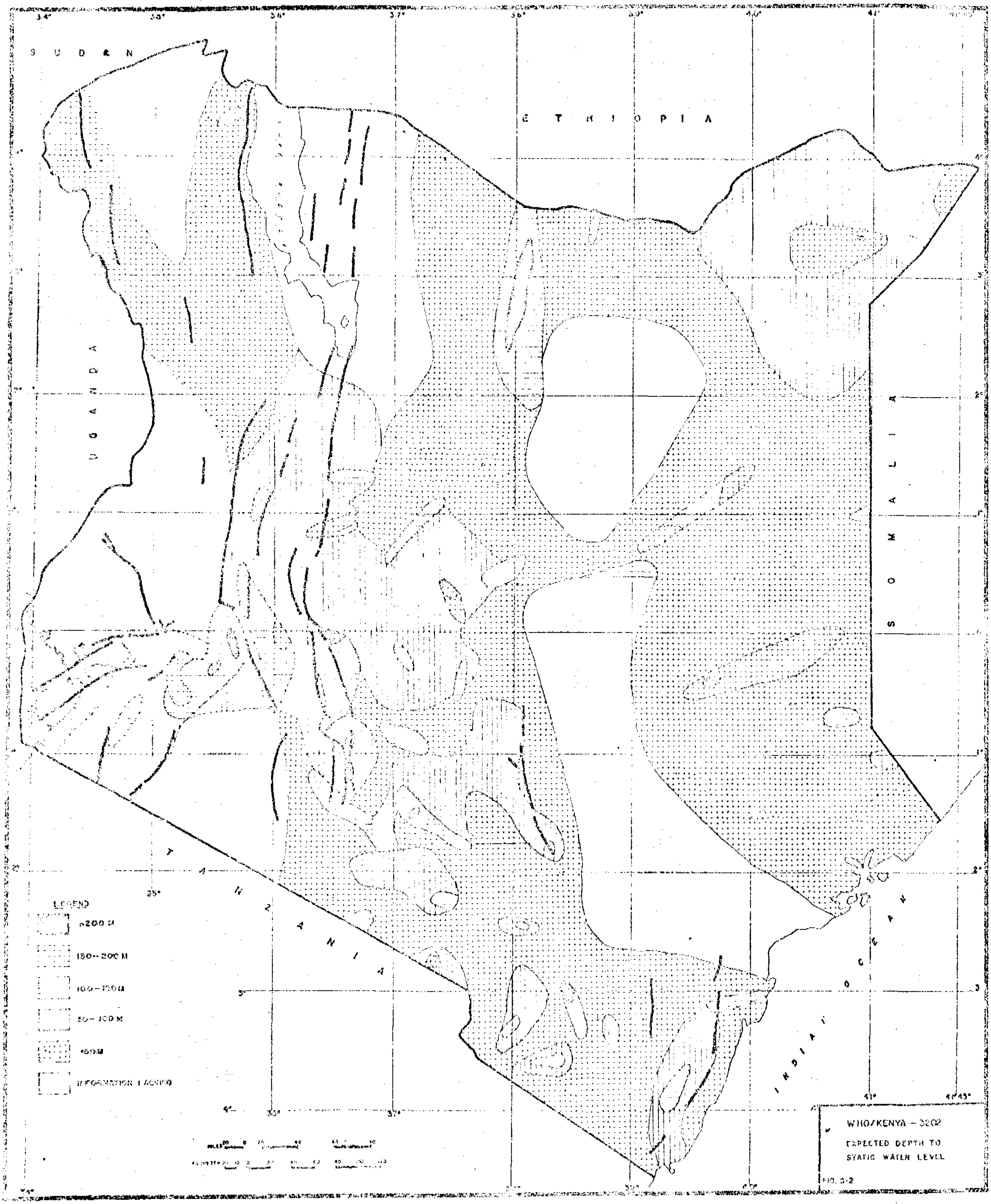
8.2 Groundwater Maps

The various groundwater maps included in this Report were compiled from borehole data stored in the offices of the Water Department. The simplified geological map (Figure 4.5) was used in interpreting the various hydrogeological parameters.

8.2.1 Quality of the Maps

A quick reference to any of the maps will reveal areas where information is questionable or altogether lacking. Some may argue that such areas should have been left blank on the maps. However, the information given for these areas is based on an extrapolation from adjacent areas as well as other complementary information.

The interpretation of available data and their interpolation in areas where they are lacking are important principles of regional mapping.



WHO/KENYA – 3202

EXPECTED DEPTH TO STATIC WATER LEVEL

FIG. 3·2

In this approach, all available data are synthesized with the published and inferred geological parameters to predict the expectations in places where data are absent.

It must be emphasized that the maps are preliminary and regional. They have been based on limited and in some cases questionable data. They should be used with caution and only as a guide to the true groundwater condition of Kenya.

8.2.2 Static Water Level

Figure 8.2 shows the estimated depth of the static water level below the ground surface. The static water level is the level of the groundwater table or piezometric surface when not influenced by pumping or recharge. In a borehole penetrating more than one aquifer with different hydrostatic pressures the static water level represents the mean hydrostatic pressure of the penetrated aquifers.

The Figure shows that the water table in most parts of Kenya occurs at less than 100 m below the ground surface. In the Quaternary areas of the east and west, as well as the Basement Complex areas, the depth is less than 50 m. In the north-east and south-east corners of the country where the older sedimentary rocks outcrop, the depth of the water table ranges from 50-200 m.

The variation in the central parts of the country adjoining the Rift Valley is great, being 50 m in certain areas and over 250 m in others. This reflects the influence of faulting, a factor that is given greater coverage in a later section of this Report.

In the volcanic areas the depth varies from less than 50 m to over 150 m. This is due to the occurrence of several episodes of volcanism as well as the occurrence of groundwater in certain areas which have been subject to diastrophic disturbances during the geological history.

The scarcity of data in western and north-western Kenya makes it difficult to predict the aquifer conditions and the map in this area is interpretational and grossly simplified.

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The locations of the available data are shown on the map and from their distribution it is evident that considerable additional data would be required before something more dependable could be inferred.

An attempt to relate the static water level to the mean sea level on a map did not provide useful information, hence that map has been left out of this Report. However, the statistics from a computer analysis of the static water level is tabulated in Districts in Appendix F.

8.2.3 Water Struck Level

The foregoing map (Figure 8.2) is essentially a piezometric map of Kenya as it defines the expected depth to the water table in the boreholes plotted. When an aquifer is struck during drilling, the water rises or falls in the borehole depending on the relationship between the aquifer and the adjoining strata. This depth is recorded as the water struck level.

The sedimentary areas in the eastern parts of Kenya are typified by near surface aquifers. Nearly half of the country where the basement and younger rocks outcrop, exhibits this property. The exceptions are the small areas in the south-east and north-east respectively. This can be explained in four ways:-

a) It is often difficult to predict the hydrogeological and geohydrological behaviour of the crystalline rocks as these depend on several variables. Local structural and lithological conditions vary widely and in turn affect the variability of these parameters. The depth of weathering together with the products therefrom are also highly variable. Hence there is no effective water table and the local pockets of groundwater storage cannot be located with conventional regional techniques. Generally, one expects the water-bearing zones in these areas to be shallow but on the basis of available data, this does not appear to be the case.

b) The structural geology of Kenya is complex and as the structural configuration has a tremendous influence on the precise location of water-bearing zones the depth from the surface also varies. Hence a fold system, growing more intense in the north-east, might have depressed the aquifers farther from the surface in the north-east than they have been towards the south. This assumes a single aquifer or a homogenous set of aquifers. From the present data, it is not possible to tell the number of aquifers involved.

c) Mesozoic sedimentation in the north-east and south-east was different and occurred in separate basins under different hydrodynamic depositional environments. Inasmuch as geology is the fundamental determinant of the hydrodynamic behaviour of groundwater, one would expect the groundwater conditions in the Cretaceous-Jurassic sediments of the north-east to be different from those in the south-east.

d) The depth to the saturated zone depends a great deal upon the area and volume of recharge. The rainfall map shows these areas are generally arid with a mean annual rainfall of less than 500 mm. Therefore with limited additional sources of recharge from rainfall, water from the saturated shallower aquifers should drain vertically into deeper less-saturated zones.

8.2.4 Piezometric Rise

The zone of saturation may include both permeable and impermeable layers of earth materials. The permeable layers are aquifers. Where an aquifer is found between impermeable layers above and below, both the aquifer and the water it contains are said to be confined. Because of the presence of the upper confining layer the water of the aquifer is not open to atmospheric pressure. It thus occurs within the pores of the aquifer at pressures greater than atmospheric. Groundwater in such a situation is said to occur under artesian conditions. The elevation to which the water level rises in a well/borehole that taps an artesian aquifer is called the piezometric surface and hence the piezometric rise is the difference between the water struck level and the water rest level.

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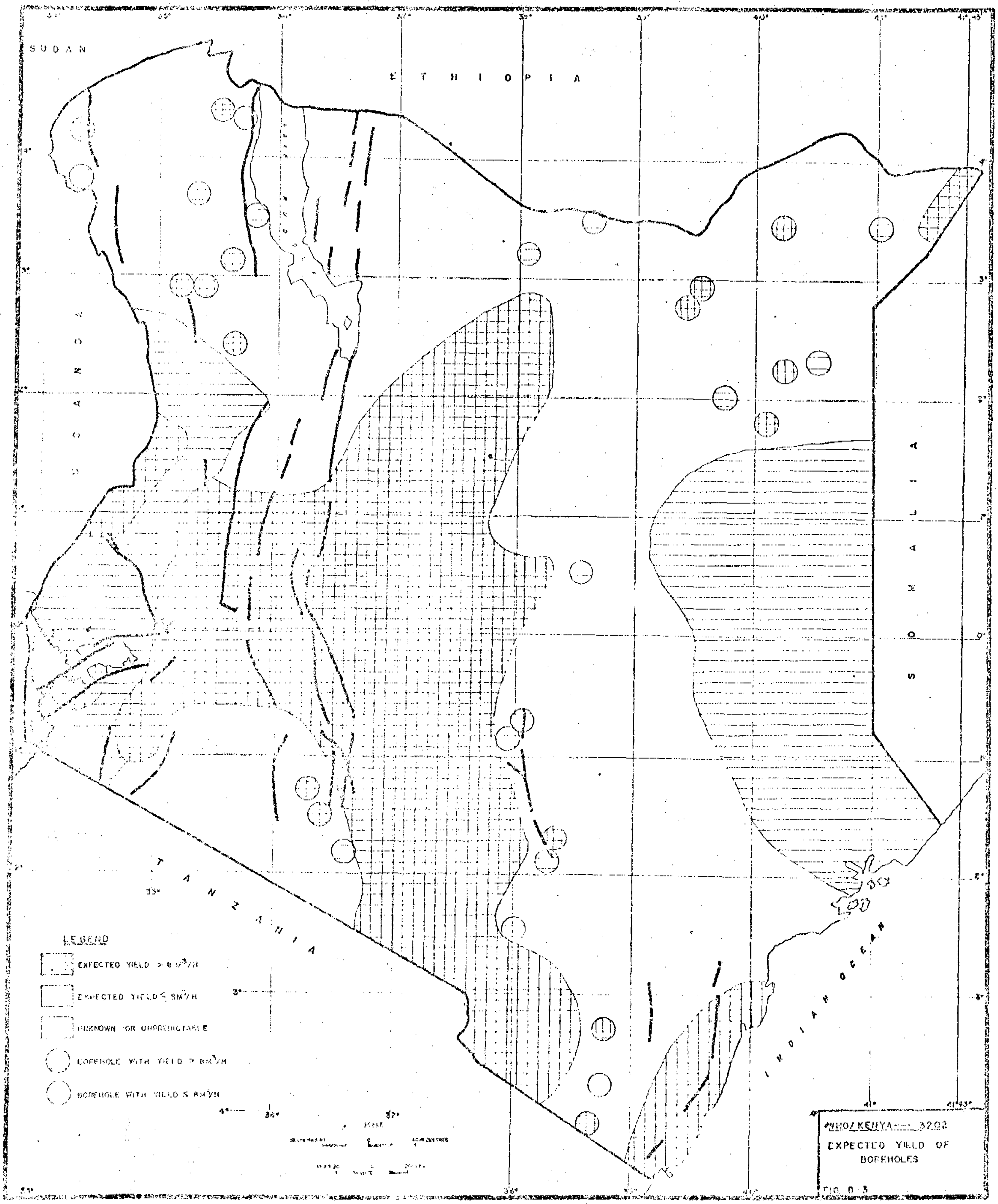

WHO/KENYA 3202

EXPECTED YIELD OF BOREHOLES

FIG. 8.3

From available data it has been observed in general that in most of the Quaternary and Basement Complex areas the piezometric rise is less than 25 m. For most of the remaining areas exceptionally high and isolated values of 100 m or more are found, especially in the tertiary volcanics of the Rift Valley.

8.2.5 Expected Yield

The input data to the expected yield map (Figure 8.3) suffers the limitation that for boreholes with high yields the values represent the pump capacity rather than the capacity of the aquifer. Hence the recorded values most probably under-estimate the capacity of the aquifers. Furthermore, different aquifers have been tested in separate boreholes and most of the boreholes penetrate several aquifers as a result that the recorded yield is a function of their individual capacities. The yield data have been expressed in m^3/hr.

The distribution of the expected yield is rather simple and typically dictated by the geology. The rocks of the Basement Complex are characterized by the least capacities. This is due to the fact that most aquifers in them are dis-continuous both laterally and vertically inasmuch as water storage in these hard crystalline rocks depends on the degree of weathering as well as diastrophic disturbances. As the depth of weathering is highly variable most probably less than 35 m, the available storage space, and hence volume of stored water, is limited.

The expected yield decreases east and north from Central Kenya, reaching 8 m^3/hr in the Quaternary areas, adjoining the Basement Complex and 8-32 m^3/hr near the coast. The expected yield in the Carboniferous and Mesozoic rocks is generally above 8 m^3/hr.

To the west the yield increases progressively. The yield decreases south into Tanzania and west into Uganda where the crystalline rocks predominate.

The boreholes in the north-west corner yield 8-20 m^3/hr and in the North Eastern Province 3-8 m^3/hr.

...27

It must be emphasized that some of the data used were collected as far back as 1927 without subsequent updating. It is recommended, therefore, that this map, like the others, be used with caution. The map should be used only as a guide and the actual situation prevailing today has to be known from test pumping.

Considerable improvement can be made to the map by pump tests, using high capacity pumps which will give information on the maximum capacities of the various boreholes.

8.2.6 Specific Capacity

Specific capacity is a valuable tool for assessing the available groundwater resources. It is the ratio of yield/draw down expressed in m^3/sec/metre of draw down (or gph/ft). When an aquifer has been penetrated and the static water level is recorded, pumping depresses the water level and the depression resulting from a given abstraction of water is the draw down. When pumping stops, the water level rises progressively as groundwater flows in from adjoining areas to replenish that which has been pumped. This rise is referred to as "recovery" and the rate is the "recovery rate".

Thick and laterally extensive saturated aquifers suffer very little draw down after releasing large volumes of water, thus showing high specific capacities; whereas unsaturated or thin and laterally restricted aquifers (e.g. perched aquifers) suffer considerable draw down even when small volumes of water are abstracted. Hence their specific capacities are low. Generally, therefore, the higher the specific capacity, the greater the available groundwater resources.

Recorded draw down data, as well as those calculated during the course of this work, represent only about 25 per cent of the boreholes in Kenya. In spite of the limitation of the yield data, the following conclusions have been drawn.

The Paleozoic, Mesozoic and Quaternary areas are characterized by specific capacities ranging from 0-1.25 m^3/hr/m (0-280 gph/ft), except for local pockets with higher figures 1.25-5 m^3/hr/m. The reason for this low figure could be that the aquifers are relatively shallow and hence drilling is discontinued as soon as the water demand is satisfied.

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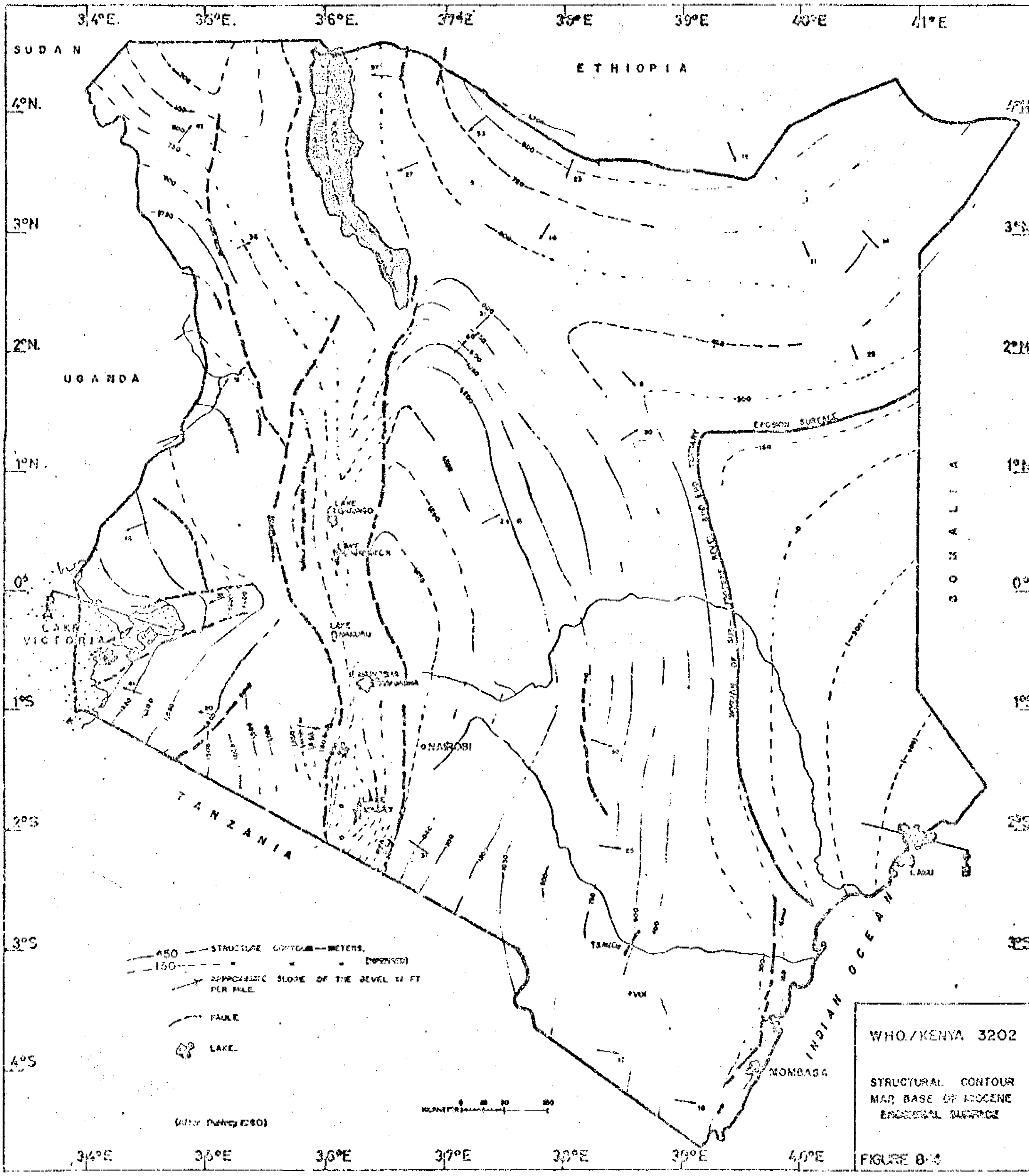
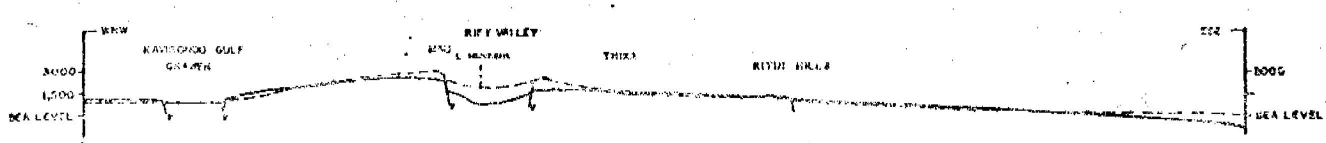




GEOLOGICAL CROSS-SECTION A-B

Deeper aquifers occur and could be tapped by deepening existing boreholes, provided the tested qualities are satisfactory.

Most of the central areas of Kenya, underlain predominantly by the Tertiary and Quaternary volcanics and sediments, are typified by low specific capacities (0-1.25 $m^3/hr/m$) although local pockets abound in which the capacity ranges from 1.25-50 $m^3/hr/m$.

Bearing in mind the scarcity and unreliability of the pump test data, it is evident that the groundwater resources potential of Kenya appear to be considerable. A better assessment will be possible only with additional pumping data which should be given priority.

8.2.7 Sub-Miocene Bevel (see also Figure 8.4)

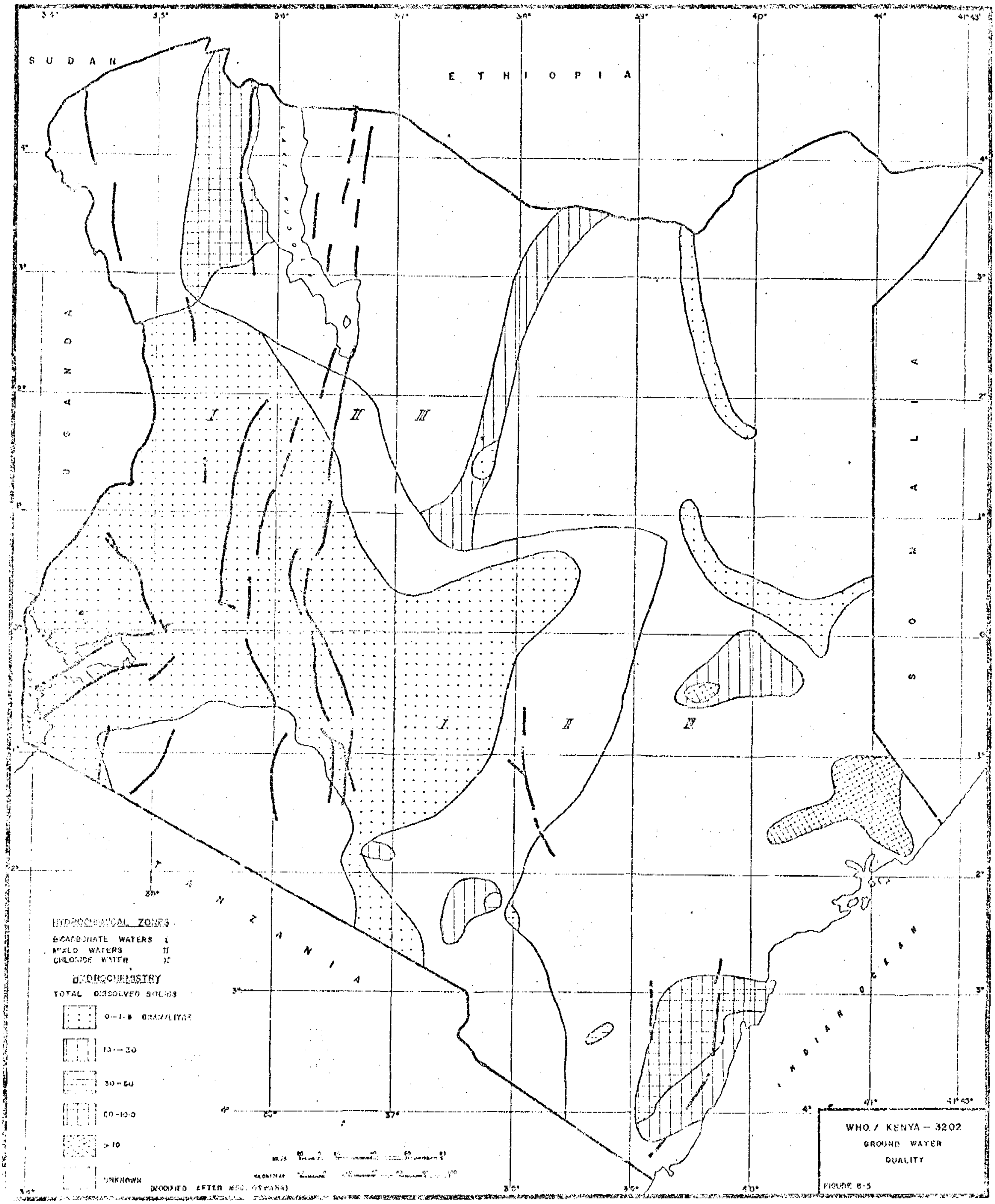
Figure 8.4 is a structural contoured map of an old weathered land surface, the sub-Miocene erosion bevel, on which lavas and sediments have been later deposited. The map is adapted from Pulfrey[1]. It reveals large uplifts in west-central Kenya split by the Rift Valley and further diversified by other grabens and faults in the west.

The "sub-Miocene erosion bevel" is well preserved north and south of Kavirondo Gulf, Masii (Machakos District) and western Kitui. The bevel slopes towards Lake Rudolf.

The map is important hydrogeologically in showing the depth to the Old Land Erosion Surface which preceded volcanic eruptions and later deposited sediments. With this map, the expected thickness of the overlaying volcanic and post-Miocene sediments can be predicted with reasonable certainty. Hence the depth to the bottom of the aquifer can be estimated prior to drilling.

...29

[1]Pulfrey, W. 1960. "Shape of the sub-Miocene Erosion bevel in Kenya."
Geol. Surv. Kenya Bull. 3, p.18


SUDAN
ETHIOPIA
UGANDA
SOMALIA
TANZANIA
INDIAN OCEAN
I
II
III
HYDROCHEMICAL ZONES
BICARBONATE WATERS I
MIXED WATERS II
CHLORIDE WATER III
HYDROCHEMISTRY
TOTAL DISSOLVED SOLIDS
0 – 1·0 GRAMS/LITRE
1·0 – 3·0
3·0 – 6·0
6·0 – 10·0
> 10
UNKNOWN
(MODIFIED AFTER ... OSTANA)
WHO / KENYA – 3202
GROUND WATER
QUALITY
FIGURE 8-5

8.3 Groundwater Quality (see also Figure 8.5)

As has been mentioned before, there are about 4 000 boreholes in Kenya, but of these only about 20 per cent have had their water chemically analysed. With an exception of the Nairobi Conservation Area boreholes (excluded on account of the small scale of the map) nearly all the others with chemical analysis were plotted on a 1:1 000 000 scale map. A "Water Quality Map" (Figure 8.5) was the outcome. This map is a simplification of a map under preparation by WD[1].

The lateral east-west general variation in the chemistry of the groundwater is clearly observable on the map. Three hydro-chemical zones can be distinguished:-

i) Zone of bicarbonate waters

ii) Zone of sulphate and mixed waters

iii) Zone of chloride waters.

Groundwater in the first zone is fresh bicarbonate type with mineralization of 120-3 700 ppm. Groundwater of this type occurs chiefly in the western and central areas of Kenya. Localized highly mineralized carbonate and carbonate-bicarbonate waters (up to 15 800 ppm) are to be found around Lakes Naivasha, Hannington and Nakuru. The presence of these is probably connected with the volcanic history of the Rift Valley. In general, however, it can be said that the total dissolved solids in this zone are within the limits stipulated in the international standards for potable water (International Standards for Drinking Water, 3rd Edition, WHO, Geneva 1971).

The second zone is characterized by a wide range of chemical composition varying from bicarbonate to chloride type, bicarbonate to chloride-sulphate type and chloride-bicarbonate types. The zone is a thin strip which widens gradually southwards. Total dissolved solids content varies from 120 ppm to 10 600 ppm. The first zone and the second zone together make up about 50 per cent of the country.

...30

[1] Oswana, R. I. 1973
Groundwater Quality Map of Kenya, Water Department
(not yet published)

The third zone comprises roughly 50 per cent of the country and extends from Lake Rudolf southwards through Samburu, Isiolo, Kitui, Taita Taveta districts and eastwards up to the Somali and Indian Ocean borders respectively. Most of the waters within this zone are typified by chloride mineralization.

Total dissolved solids within the zone vary from 1 g/l to 35 g/l. The waters with the highest mineralization are found in alluvial deposits of Quaternary age and in the Permo-Carboniferous sediments.

Fresh bicarbonate waters with total dissolved solids varying from 0.4 to 1.2 g/l are encountered in boreholes between depths of 90 to 150 meters in the area which trends north-west-south-east and also along the coastal belt in the shallow wells.

A large part of this zone can not yet be represented from the hydrogeological point of view because of lack of data.

8.3.1 Distribution of Fluoride in Kenya Groundwaters

Figures H1 (Lupilli, 1972) and H2 (Murithi, 1971) in Appendix H show the distribution of fluoride content in the groundwater of Central Kenya and the Nairobi Conservation Area.

Highest concentrations occur in Nairobi area as well as in the Rift Valley around Nakuru and Naivasha with maximum values up to 40 ppm. Local pockets of intermediate concentrations (2-10 ppm) are scattered throughout the country. Considerable additional data on fluoride content is required before mapping can be done on a countrywide basis.

Figure C2 is a more detailed assessment of the distribution in the Nairobi Conservation Area. This is a modified form of the map prepared by Murithi (1971). It shows that about half of the conservation area stores groundwater with higher fluoride content than is recommended by international standards (over 1.5 ppm).

The high fluoride content is related to the geology, particularly of the Rift Valley area. The extensive and complex pattern of faulting has been an important factor in disseminating the high fluoride waters to areas where they are not expected. It is believed that the fluoride content has an origin in the volcanic and fumarolic gases, rather than in the degradation of fluoride, although no field evidence has been accumulated during the course of this study to support this contention. The geology, distribution of fluoride in the geologic systems, relation of the high-fluoride waters to the volcanic rocks, hot springs, geysers and fumaroles, leave little doubt that this is most probably the case.

Fresh chemical analyses should be carried out on existing boreholes with higher than optimum fluoride levels and if new data confirm that previous ones, such waters should be defluoridated to protect the populace utilizing them.

8.3.2 Defluoridation

Several methods are used to reduce the high fluoride concentrations to the required optimum levels. The easiest method is the blending of high and low fluoride waters in pre-determined proportions. A second, more expensive, method is the use of several chemical processes. Thus the use of tricalcium phosphate, activated alumina, bone char and bone meal, removes fluoride ion with varying success through a combination of sorption and ion-exchange processes. Dolomite, dissolved and converted to $Mg(OH)_2$ is also used, but it requires 40-60 ppm Mg to remove 1 ppm fluoride and so becomes rather expensive.

A recent advance in the process of defluoridation was made by the Central Public Health Engineering Research Institute of India (CPHERI)[1]. A prototype of the plant (Defluoron 2) was tested in the Department of Civil Engineering of the University of Nairobi (Lupilli, 1962)[2] and it was concluded that the Indian experience is applicable to Kenya.

... 32

[1] Cpheri, 1969 " 'Defluoron-2' - A new medium for the reduction of Fluoride in Water Supplies"
Environmental Health 11, 108

[2] Lupilli, R.M. 1972 "Defluoridation by 'Defluoron-2'"
Unpub., B.Sc., Spec. Proj. Rept.
Dept. Civil Eng., Univ. of Nairobi

The laboratory experiment showed the removal capacity to be 140+10 mg/1 (ppm) of F- for the medium at 290 mg/l alkalinity as $CaCO_3$ using a raw water sample with 8-9 ppm F-content at a flow rate of 5 m^3/m^2 bed area/hr.

The estimated cost for a plant of 45 000 l/d (10 000 mpd) designed to reduce the fluoride content from 8-1.5 ppm worked out to K shs 6/50 per 1 000 gallons.

8.4 Tentative Hydrogeological Zones

Inasmuch as the water-bearing and transmitting capacities of rocks are the principal attributes of hydrogeological investigations, the complex geology of Kenya (Figure 4.5) can be considerably simplified as shown in the map indicating Tentative Hydrogeological Zones. (Figure 8.1)

The storage capacity of a rock is a function of the lithology and the age of the rock plays only a minor role. Thus two sandstones of Tertiary and Quaternary age respectively, with identical granular properties, would possess similar aquifer characteristics. Variation in age of the rocks becomes important only in very old systems where post-depositional alternations have adversely affected the primary porosity of the rocks.

On this basis, therefore, the hydrogeological map of Kenya can be regarded as a considerably simplified geological map in which rocks of similar hydrogeological characteristics are classified together. On the basis of the foregoing presentation, six hydrogeological provinces can be outlined:

a) Eastern Quaternary Sedimentary Areas

b) Basement Complex Areas

c) Older Sedimentary Areas

d) Volcanic Rock Areas outside the Rift Valley

e) Volcanic Rock Areas in the Rift Valley Area

f) Western Quaternary Sedimentary Areas

Major borehole statistics (depth, yield and specific capacity), tabulated on the basis of rock types, are presented in Appendix G. The Appendix shows that boreholes in the volcanic areas are deepest, while those in the sedimentary areas are shallowest. The yield is highest for the volcanic rocks and lowest for the Basement Complex, whereas the specific capacity is highest for the sedimentary rocks and lowest for the Basement Complex.

8.4.1 Eastern Quaternary Sedimentary Area

This area accounts for nearly 30 per cent of the surface of Kenya (Figure 8.1), stretching essentially from latitude 4°S to 3°N and as far west as longitude 38°E. Alluvial, lake and beach sands, coral reefs and limestones, (some fresh water type) dominate the lithology.

The sediments are loose and permeable and hence recharge from rainfall, groundwater flow from other areas where the water table occurs at high elevation, as well as percolation from other surface water sources, is important. Spring discharge is common, particularly along the shore and is useful in borehole siting.

A good account of the geology and hydrogeological conditions of this zone is covered in a report by Gentle[1] (1965) to which the reader is referred for additional details.

HYDROGEOLOGY:

According to Reeve[2] the main aquifer appears to be the fringing coral limestone, whereas additional data led Gentle to conclude that sands form the major aquifer. These are Pleistocene sands underlain by Jurassic shales which stop downward percolation and cause a net flow in the coastal direction due to a general gentle coastward dip.

...34

[1] Gentle, R. I. 1965 "Hydrogeology of the Coastal Strip between Gaza and Mtwapa, Kenya Coastlands". Tech. Paper 3, Water Dept.

[2] Reeve 1949 "Groundwater Investigation in Nyali-Kizauni-Shima la Tewa Area, North Mainland, Coast Province"

The aquifers are generally shallow and unconfined and the success ratio, at least in terms of locating adequate quantities of groundwater, is very high. Old lake sites are common in this area. The lakes are believed to have dried up during the Holocene and their sediments are generally saturated with water.

Gentle has, with considerable success, applied the resistivity technique to the coastal area. Inasmuch as the resistivity of an aquifer is affected by five main factors - degree of saturation, type and amount of dissolved solids, porosity, fluid viscosity, and resistivity of sediment particles, it is obvious that this method should succeed in the coastal region where the geology is simple and the presence of saline waters contributes to the ionization of the groundwater. Using a Tinsley-Paver Earth Resistivity Potentiometer, a Wenner electrode spread of 3-100 m spacing, and a standard matching technique (Mooney and Wentzel, 1956) he succeeded in defining, fairly accurately, the stratigraphic succession and in defining the fresh and salt water zones.

The Lamu Island presents an interesting problem in this area. The water needs of Lamu Island are increasing every day to keep pace with the growth of the tourist industry. This increases the danger of sea water intrusion through over-pumping of existing wells. It is recommended that an investigation of the available water resources be immediately determined to see if new wells can be dug.

An unpublished report (Selby, 1969) on the Lamu Water Supply shows that the island (2°S, 41° 30'E) is supplied by twenty shallow fresh water wells along a line of sand dunes about two miles south of Lamu town. They were designed for a maximum abstraction of 178 cubic metres (40 000 gallons) per day.

As can be expected, the fresh water floats on the heavier salt water, which is very close to the surface - in most cases, less than five metres from the surface. The average height of the sand dunes is 10-13 metres above mean sea level.

On account of the expected increase in tourism, the water demand on the island has also increased, leading to pumping below the recommended depths from the surface and above the designed maximum daily abstraction rate. Should this continue unchecked, the reservoir may be irrevocably damaged through sea water intrusion.

WATER QUALITY:

The greater problem in groundwater development in this area is that of salt water, which has caused the failure of several boreholes.

There is evidence of increased saline water contamination in some boreholes. Wells sampled in 1951 by Miles and in 1965 by Gentle, showed 890 ppm and 1 225 ppm respectively, of total dissolved solids. The fluoride content is less than 2 ppm everywhere.

The waters are generally of chloride type with intermediate pH. Alkaline waters with pH - 8 occur close to the coast. The detailed chemical data of all the boreholes in the north-east Province are presented in Appendix I and those of the samples collected during a visit to the coastal region are presented in Appendix K. They indicate that higher (total dissolved content) salinity is typical of deeper aquifers and that the shallower aquifers generally contain fresh water.

ORIGIN OF SALINE WATER:

Figure 8.6 shows the effects of changes in sea level during the Pleistocene Epoch. It is evident from this diagram that a progressive influx of sea water can be expected at the coast and that most of such inflow would be trapped in topographic and structural depressions in the Pleistocene sediments. The occurence of fringing reefs also helps the trapping of sea water in inland areas. Hence the saline water of the coastal region appearing to be dominantly of recent origin.

Three important parameters for characterizing water quality are presented in Figures in Appendix L. The maps, derived from Gentle (1965) show the distribution of the $\frac{Cl}{HCO_3+CO_3}$ ratio (Figure L1), total dissolved solids (Figure L2) and chloride content (Figure L3) along a coastal strip about 5 km wide from Gazi to Mtwapa. The three maps show a higher degree of sea water contamination at the coast, decreasing progressively landward.

HYDROGEOLOGY:

Miles (1951 b) estimated the groundwater velocity to be of the order of 0.03 m/d in a general coastal direction and Gentle estimated the specific yield to be about 30 per cent. According to Gentle (1965) the areas of best quality water along the coast are under-exploited, whereas those of poor quality water are over-exploited. By 1965, nearly 1 200 m^3/d was being abstracted north of Mtwapa Creek, 91 per cent of which came from a well (1 100 m^3/d - 240 000 gpd) with a total dissolved solids content of 1 916 ppm. The abstraction rate was 11 600 m^3/d (2 560 000 gpd) in the south mainland area.

In order to avoid further deterioration of fresh water through sea water intrusion, it is suggested that heavy pumping should only be permitted where the Cl/HCO_3+CO_3 ratio is very much lower than 1.0. Detailed test pumping is also required to ascertain places where heavy pumping is advisable. Gentle (1965) advised that the coastal area be declared a conservation area. This study is in full agreement with that recommendation.

Farther inland, however, there are certain areas where boreholes tap nothing but salt water. Two of these general areas are shown in Figure 8.6. Salty groundwater in these areas is only slightly due to sea water intrusion. The bulk is of connate origin, arising from the trapping of ancient sea water of an extensive pre-Pleistocene sea.

Salt water of connate origin is not, however, very extensive laterally and has been influenced by present day surface drainage. This is evident in Figure 8.6 and Figures in Appendix L where groundwater of lower total dissolved solids is associated with the Athi, Tana and Ewaso Ng'iro drainage basins.

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8.4.2 Basement Complex Areas

Rocks of the Basement Complex are widely distributed throughout the country, occurring mainly in the central, western and north-eastern parts of Kenya, with small exposures in other parts. Altogether this hydrogeological zone covers about 25 per cent of the country.

The lithology is dominated by granites, granitic rocks, schists and less-metamorphosed sediments. They are deeply weathered in most places, although the depth of weathering is not uniform throughout the country. It is this phenomenon of weathering, together with the strong and complex diastrophic disturbances associated with the formation of the Rift Valley system, that is responsible for creating storage spaces for groundwater accumulation.

HYDROGEOLOGY:

The available groundwater resources of every Basement Complex area are difficult to predict because the two most important hydrogeological parameters necessary for water storage (porosity and permeability - in the pre-existing sedimentary rocks) are destroyed or significantly changed by later processes that convert them to metamorphic rocks.

Deep chemical decay typical of warm equatorial climates are, however, important in creating secondary porosity for water storage. This, together with tectonic movements, has helped in ensuring relatively good groundwater storage in the basement rocks of Kenya.

The aquifers are shallow and discontinuous, both vertically and laterally. Perched aquifers are typical as they are in most crystalline rocks. Where faults and fracture zones are extensive both laterally and vertically, groundwater tables occur, sometimes in rather deep horizons. Although not typical of most of the area, confined aquifers do not appear to occur in these rocks, resulting from lithological displacements occasioned by faulting. Weathering in places has a negative effect on water storage through the reduction into clays.

Few boreholes are deeper than 160 m and it is usual to abandon drilling after a depth of 115 m has been reached. Boreholes in valley bottoms often strike weathered or alluvial zones several metres thick but as most of the rocks are feldspathic, the "aquifer" zone is usually located at the base where the rocks are only partially decomposed and clay formation has not strongly reduced permeability. Aprons of residual hills may be sufficiently thick to serve as good aquifers.

WATER QUALITY:

Water in this zone is generally good unless contaminated by man-made effects as in the case of the discharge of domestic, industrial and agricultural (fertilizers, pesticides) effluents. This results from the shallow unconfined nature of the aquifers.

The water is generally hard with moderate total dissolved solids. The fluoride content is generally below the limits set by the World Health Organization.

EXPLORATION FOR GROUNDWATER:

The location of water in the Basement Complex requires more than the routine techniques used for sedimentary rocks, which more often than not, contain adequate volumes of groundwater. The combined use of conventional hydrological, geological and geophysical techniques, is the most certain means of borehole siting in these areas.

The use of electrical resistivity technique is common in Kenya. However, experience in West Africa[1] under similar conditions indicates that the use of shallow seismic techniques could probably be applied in Kenya with success. This depends on the principle that the best site for locating water is the area of thickest superficial cover which may occur in the form of <u>in situ</u> weathered materials or in ancient river channels (buried alluvium) and old lake sites. The seismic refraction technique can be successfully employed in determining the thickness of such superficial materials overlying the hard rock, as well as fissures and faults in hard rocks.

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[1]Asseez, L.O. 1972 "Rural Water Supply in the Basement Complex of Western State, Nigeria": Bull. Int. Assoc. Hydrol. Sci. XVII, 14/1972

Although it is unlikely that large volumes of water required for major industrial and urban supplies can be expected from the groundwater resources of this zone, adequate supplies can be obtained therefrom for rural settlers.

8.4.3 Older Sedimentary Rock Areas

Sediments of Paleozoic and Mesozoic systems occur in the south-eastern and north-eastern corners of Kenya. They were formed in two separate depositional basins with different environmental features as evidenced by their different fossils. The geological, stratigraphic and structural settings are outlined in later pages of this Report (Appendix D).

The lithology varies widely and the three major sedimentary rock types (sandstones, limestones and shales) are represented in the basins.

HYDROGEOLOGY:

The rocks in this hydrogeological area are characterized by parameters suitable for groundwater storage. They show extensive areal and vertical distribution.

Aquifers in them are numerous, typically confined and deep. Considerable folding and faulting is believed to have occurred during the geologic periods represented. The water quality is good.

8.4.4 Volcanic Rock Areas outside the Rift Valley

Several episodes of volcanic activity are recorded in the geological history of Kenya. The earliest eruption was in the Miocene. Eruptions took place from then until the Recent and there is evidence that some of the vents are only dormant and may erupt any time in the future.

The volcanic rocks cover about 25 per cent of the surface of Kenya, but more commonly in Western Kenya where they exhibit a linear alignment with the Rift Valley system. The general pattern is north-south, stretching from Tanzania into Sudan and Ethiopia.

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The lithology is widely variable and includes phonolite, trachyte, tuffs and basalts. Groundwater storage in both Tertiary and Quaternary volcanics is similar and hence the lumping of the two systems into a single hydrogeological unit. Water is stored most typically in the old weathered surfaces between lava flows and older formations as well as between successive flows. Fractures, faults and contraction joints are also suitable zones for water storage and these are often important, particularly in the highly disturbed areas surrounding the Rift Valley.

Red earths, a product of weathering, typically cover the rocks in places. The soil cover on phonolites is thin, generally free-draining and possesses friable texture. Pink and brown soils may also occur, but not commonly.

HYDROGEOLOGY:

The volcanic rocks west of the Rift Valley consist of phonolites and tuffs and are mainly of Tertiary age except for south of Njoro where they are mainly Quaternary. The groundwater occurs mostly in the weathered zones between the Basement Complex and the overlying volcanic rocks. The thickness of the volcanic overburden varies from nil to several hundred metres and hence the groundwater is to be found at varying depths. Groundwater may also occur within the volcanic formations mainly in zones between volcanic rocks of different type. This also means that several aquifers may be struck in a borehole.

A maximum thickness of 620 m of the phonolitic lava is recorded at the border to the Rift Valley at Tambach. The thickness decreases to the west. The underlying volcanic ashes, tuffs and grits were according to fossil evidence deposited in early Miocene.

The volcanic areas east of the Rift Valley are mostly of Tertiary age while Quaternary volcanics occur still further east.

The rocks consist of phonolites, tuffs, agglomerates and basalts, the phonolites being the dominating rock.

The volcanic rocks overlie the old weathered land surface, the sub-Miocene erosion bevel, the thickness being estimated to be about 1 100 m. The rocks are characterized by variable permeability which seems to reach highest values near the volcanic vents. The lavas in general contain contraction joints and weathered zones thus having rather a good permeability. The tuffs have lower permeability due to absence of contraction joints and in addition often due to decomposition into clay.

Yield, depth to aquifers and static water level vary enormously within the volcanic rocks. Several aquifers may be struck in a borehole. The aquifers are usually confined. In the eastern Quaternary volcanic areas the artesian pressure is 5-20 m with a few boreholes with higher values up to a maximum of 185 m.

In the western Tertiary volcanics the range is wider, from 5-100 m, with a few exceptional values up to 125 m.

The yield from boreholes in the Quaternary volcanics is lower than in the Tertiary and is in the magnitude of 3-20 m^3/hr. In the Tertiary volcanic rocks the borehole yield increases from north towards the south, being less than 3 m^3/hr in the north and more than 32 m^3/hr in the south. (See maps 4.7 and 8.2).

GEOPHYSICAL PROSPECTING FOR GROUNDWATER:

It was established by McCall (1957) in his work in Nakuru area that electrical resistivity is not good for volcanic areas. This same conclusion was reached by Bristow (1962) for phonolites and tuffs. This, according to Bristow, was due to several factors, important among which were:

a) presence of clay beds giving rise to greater resistivity anomalies than aquifers

b) presence of groundwater in permeable formations overlying aquifers

c) depth to main aquifers being greater than that to which resistivity curves can be interpreted

d) presence of highly conductive layers of black cotton soil which distorts resistivity curves.

Both seismic and electrical resistivity explorations have been used in selecting suitable sites for drilling. In one programme at Archer's Post, Marsabit, 101 electrical soundings were made with maximum AB lengths of 400-600 m in Lerata River sector. All the resistivity variations reflected the depth to conductive layers as well as facies changes; it was possible to calculate the thickness of the conductive layer from these. Five borehole sites were recommended from this study, but only one drilled at the recommended site proved successful. The other four failed, most probably because they were not drilled where recommended.

GROUNDWATER MOVEMENT IN THE SOUTH-EAST:

The Mzima Springs, with a flow exceeding 3 m^3/sec (100 cusecs) dominate the surface flow of the lava country of south-eastern Kenya around the Chyulu volcanoes which lie about 64 km north-east of Kilimanjaro. There is no surface drainage apart from nine other smaller springs. It is believed that groundwater flow in this area is generally in the south-east direction because 90 per cent of the spring discharge takes place in the south-eastern areas of this lava field. The surface of the Basement Complex also slopes in this direction, hence directing the sub-surface flow of the groundwater. Hence rain water percolates rapidly vertically until it reaches the crystalline Basement Complex along which it flows according to the slope of the surface (Figure 8.4). The groundwater flow in this area is believed to simulate the surface water flow that occurred before the Tertiary-Quaternary volcanic activities.

WATER QUALITY:

The water in the volcanic areas is generally bi-carbonate type with low total dissolved solids. However, there are local pockets of high fluoride content. Hence, adequate sampling of individual major aquifers is necessary to determine borehole completion features that may be needed to preclude the mixing of high fluoride groundwaters with low fluoride types.

8.4.5 Volcanic Rock Areas in the Rift Valley

The effect of rock structure on the groundwater storage is very clearly exemplified by conditions occurring in this hydrogeological area. Although the lithologic conditions in the Rift Valley zone are similar to those prevailing in the adjacent areas, the complex structural character of the area has modified its water storage properties. It is therefore pertinent to classify it as a different hydrogeological province.

The zone is pear-shaped and extends from the Basement Complex areas near the border with Tanzania in the south to the southern tip of Lake Rudolf.

The geology is dominated by Tertiary volcanics while the Quaternary volcanics represent the second most wide-spread rock type. A few pockets of the Basement rocks and Quaternary sediments are also found.

The structure of the Rift Valley dominates the region and in fact forms the criterion for classifying the region as a hydrogeological unit.

HYDROGEOLOGY:

The groundwater resources of the area seem to be large but the location and sometimes the exploitation is difficult and often expensive. Depth to the groundwater and yield cannot be predicted with certainty because rock displacements can be of the order of a hundred metres or more, thus bringing the aquifers nearer to, or farther away from, the surface. A borehole penetrated deep enough, is certain to tap large volumes of water in one form or another (e.g. cold or hot water, or steam).

EFFECT OF FAULTS:

The complex pattern of faulting and cross-faulting can be resolved into a simple system trending SE-NW in the southern parts of the area and later swinging right until they are aligned almost north-south. These faults affect not only water storage, but also the pattern of its migration and consequent discharge.

The fault planes are sometimes filled with impermeable materials which act as barriers to groundwater movement and often surface discharge - springs. In the eastern areas the faults serve as aquifers.

If a stream flows parallel to a fault plane in high ground, groundwater recharge takes place; the reverse (discharge) takes place into the stream in low ground.

WATER QUALITY:

Hot springs and geysers occur commonly in this region evidencing active geothermal activity. There is evidence of large sub-terranean plutonic bodies still in their final stages of cooling. These continue to provide the necessary source of heat and pressure build-up, all of which contribute to the modification of the groundwater chemistry.

The water is typically bicarbonate type; the fluoride content, however, is high in places. The fluoride is believed to be of volcanic and fumarolic origin and hence the ion should be expected to increase towards volcanic vents.

THERMAL GROUNDWATER - RIFT VALLEY:

A comprehensive study was reported by McCall[1] (1957) on the distribution of thermal waters in Nakuru-Thomson's Falls-Lake Hannington area. Since then another study has been carried out by Balfour Beatty[2] (1965).

A UNDP Project is currently carrying out a feasibility study of the utilization of thermal groundwater for power production in the vicinity of Lakes Naivasha, Hannington and Elementaita. A draft report from the Project[3] gives a comprehensive picture of the groundwater in this part of the Rift Valley area.

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[1] McCall 1957 "Geology and Groundwater Conditions in Nakuru Area." MOW Techn. Rep. 3

[2] Balfour Beatty & Co Ltd, 1965 "Rift Valley Steam Project" Kenya Govt. Rep.

[3] UNDP Geothermal Project. "A Preliminary Hydrogeologic Evaluation of the Long-Term Yield of Catchments related to Geothermal Prospect Areas in the Rift Valley of Kenya".

The Rift Valley area is typified by internal drainage and no rocks older than Tertiary are exposed. There are mostly volcanics and sedimentaries of Tertiary and Quaternary age.

Water is struck at several levels in fresh phonolite, in porousal old land surfaces and in weathered phonolite. In the eastern parts of the area, the water table occurs about 65 m from the surface and sub-artesian conditions are common.

The tentative conclusions about geothermal water in the McCall Report were:

a) The geothermal waters occur along major fracture zones.

b) They are absent where Plio-Pleistocene movements and volcanicity are absent.

c) They are especially associated with quiescent volcanic craters where linear arrangements are apparent.

d) There is no apparent connection between thermal phenomena and recent lavas which are still cooling.

e) There is a definite increase in thermal activity near large Plio-Pleistocene volcanoes.

f) There is a close connection between hot springs, fumaroles and surface waters. For example, hundreds of hot springs occur on the edge of flowing streams in Lake Hannington.

Some of the conclusions in the 1972 UNDP Report on groundwater in geothermal prospect areas in the Rift Valley were:-

"i) The main groundwater reservoir that supplies water to most wells in the area occurs at depths ranging from 30-150 m.

ii) Yields of most wells are very low and range from 2.5-13 cubic metres per hour.

iii) The hydraulic relationships between the upper currently developed aquifers and the deeper geothermal reservoir is unknown and extensive exploratory drilling may be needed to definitely establish geothermal recharge areas."

8.4.6 Western Quaternary Sedimentary Areas

The foregoing account for the Quaternary zone in the east applies to the other areas of similar sedimentation.

The differences are seen only in water chemistry and depth to the aquifer. In these other areas, fresh, shallow water conditions exist in all Quaternary areas south of the Equator and immediately north of it, where adequate recharge from rainfall occurs. In all other areas - around Lake Rudolf and in the north-west corner - groundwater horizons are deeper than they are in the Coast. On account of the higher rate of evapotranspiration and less recharge from rainfall, the water is moderately saline but possible potable.

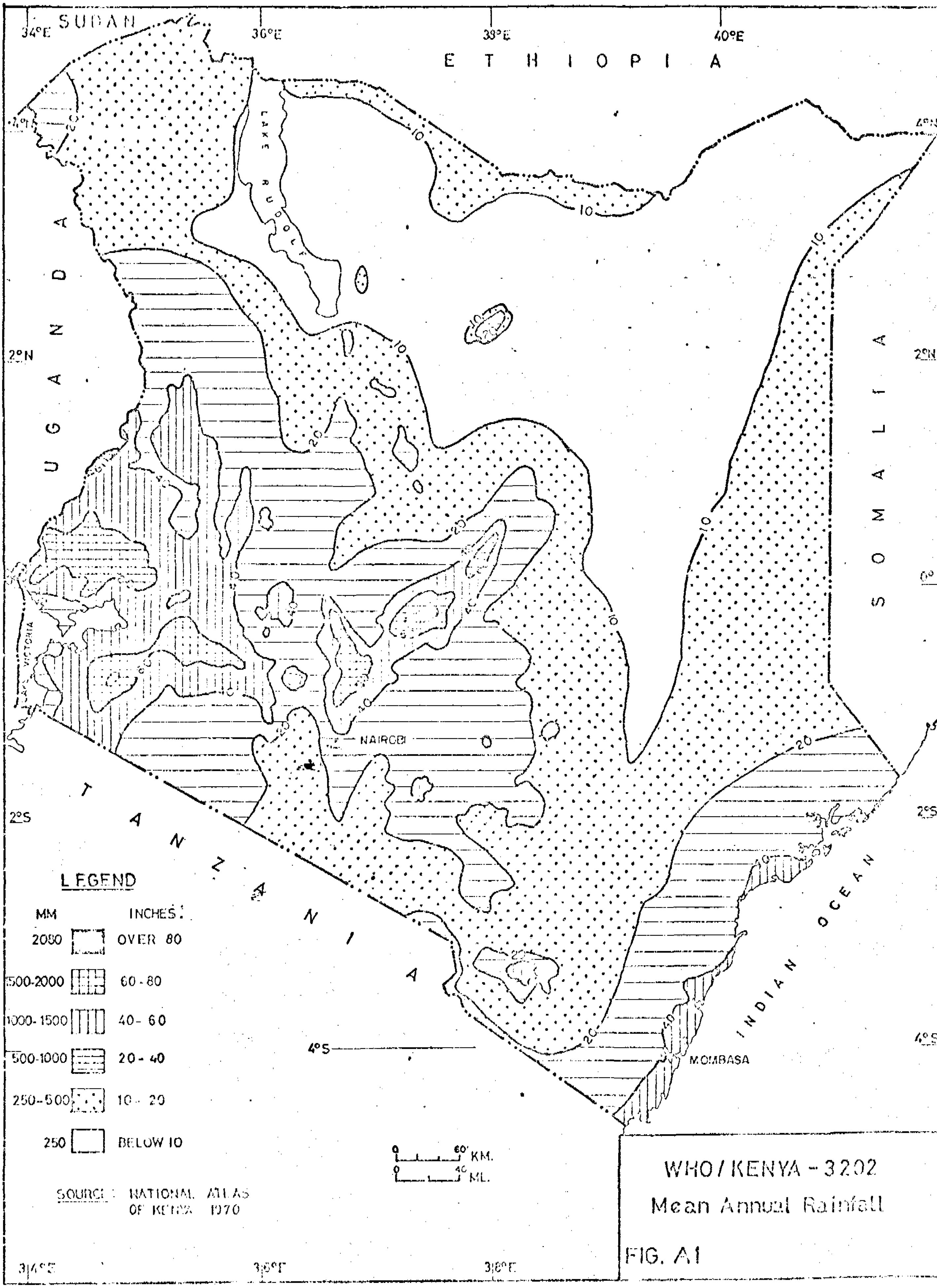
8.5 Groundwater Pollution Control

About half of the country (eastern half) is covered by permeable soils, mostly sediments. This together with a water table not far below the ground surface makes in necessary to pay attention to the danger of pollution of the groundwater from sewerage, petroleum products and other pollutants.

On the other hand, parts of the country have the groundwater table at great depths with artesian conditions which will reduce the danger of groundwater pollution. These widely different conditions make it necessary to take into account the hydrogeological conditions in the different parts of the country when pollution aspects are considered.

APPENDIX A

Mean Annual Rainfall



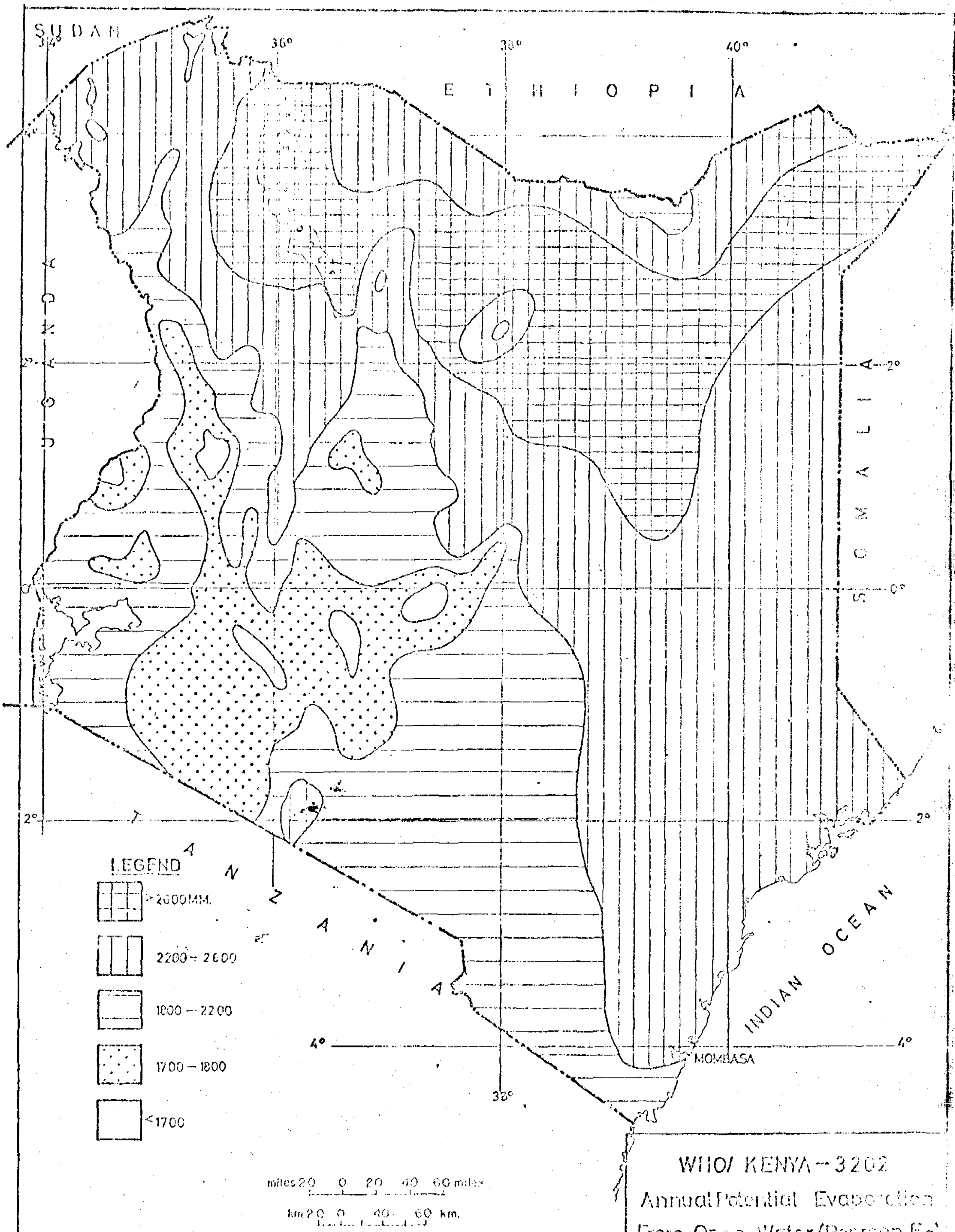
WHO/KENYA-3202

Mean Annual Rainfall

FIG. A1

APPENDIX B

Potential Evapotranspiration



WHO/ KENYA – 3202

Annual Potential Evaporation From Open Water (Penman Eo)

Fig. B1 Appendix B

APPENDIX C

Stratigraphic Chart

APPENDIX C

TABLE C1

STRATIGRAPHIC CHART OF KENYA

ERA	SYSTEM		LITHOLOGY	MAJOR TECTONIC EVENTS
CENOZOIC	QUATERNARY	RECENT	Soils, alluvial and beach sands. Magadi, soda lake spring deposits. Alkaline lavas and pyroclastics.	Volcanicity, eustatic changes in the sea level, minor faulting.
		PLEISTOCENE	Coral reefs, sandstones, terrestrial limestones, lignite beds, Alkaline lavas and pyroclastics.	Grid faulting, vulcanicity, East and Kavirondo Rift faulting, vulcanicity.
	TERTIARY		Clays, sands, sandstones and conglomerates. Terrestrial limestones and sediments. Alkaline lavas and pyroclastics.	Faulting, warping, vulcanicity and early development of East Rift Zone.
MESOZOIC	CRETACEOUS		Sandstones, siltstones, shales and limestones. Freretown lst, Marehan Ss, Danissa Beds.	Regional uplift (610 m in central Kenya). Peneplanation.
	JURASSIC		Daua lst Series, Mandera Series (lst, Sh. ss. siltstones and mudstones)	Slight warping, tilting and faulting of Mesozoic seds.
PALEOZOIC	KARROO		Duruma Ss, Mansa Guda formation. Tillite, grits, Ss, Cgl. siltstones and lst Sh.	Gentle eastward tilting, warping and faulting of Duruma Ss. and Mesozoic seds. at the coast.
PRECAMBRIAN	BUKOBAN		Acid-basic volc. qtzite + sediments Kisii Series.	Gentle warping and minor faulting.
	KAVIRONDIAN		Argillaceous % arenaceous sediments cgl, hornblende granites	Metamorphism, granitic intrusion. Isoclinal folding with NE and SE axes.
	NYANZIAN		Ablum series, Cgl Ss qtzites, lst phyllites. Embu Series Ss lst Cgl, pellites. Samia Hills Series Basic volcanics, ironstones.	
	BASEMENT		Qtzites, lst, gneisses, schists charnockites. Turoka, Kasigu Series plus Gobo Fm.	Folding

APPENDIX D

General Geological Description

APPENDIX D

GENERAL GEOLOGICAL DESCRIPTION OF KENYA

1 GEOLOGY

All the four major Eras (Precambrian-Cenozoic) are represented in the complex geologic column of Kenya, the best known of which is the classical Rift Valley system, which is believed to have developed in Kenya in the Tertiary Period. The lower portion of the column is represented by volcanics as well as igneous and metamorphic complexes divided into four major systems, most of which are Precambrian in age.

The Paleozoic is represented by the Permo-Carboniferous Karoo System whereas only the Mesozoic is well developed in the north-east and the south-east. The Cenozoic is probably the best developed and most important in terms of surface coverage and is represented by sedimentary and volcanic rocks of Tertiary and Quaternary deposition.

1.1 The Precambrian Rocks

The crystalline (Precambrian) rocks are divided into four systems: Basement, Nyanzian, Kavirondian and Bukoban (Figure 4.7).

The Basement Complex is composed mainly of metasediments (grits, sandstones, shale, limestone) metamorphosed by heat, pressure and hydrothermal fluids, as well as metamorphosed rocks of volcanic origin. The presence of high grade schists, gneisses, graphite, quartzites, marble granulites and migmatites evidence the high degree of metamorphic alteration.

The Nyanzian System is represented by great thicknesses of lava flows, pyroclastics and, in places, by lenses of conglomerates and banded ironstone.

The Kavirondian System is most typically developed in the northern and central areas of Nyanza Province and consists of alternating bands of grits, sandstones and shales which are only slightly metamorphosed.

The Bukoban is composed of a three-fold upper and lower lava series separated by quartzites and although the age is uncertain, it is definitely younger than Nyanzian or Kavirondian and is probably Precambrian. Precambrian granites of granitized and intrusive origins are widespread in Western Kenya. Around Lake Rudolf basanites and olivine nephelinites are well developed, whereas carbonatites occur near Lake Victoria, Mrima Hill south of Mombasa and at Mount Elgon.

1.2 Karoo System

The Karoo System of Permo-Carboniferous age occurs in south-eastern Kenya where it is represented by the Taru Grits – a monotonous series of grits, sandstones, shales and traces of coal.

1.3 Mesozoic Rocks

The Triassic System is divided into two: Upper and Lower, in south-eastern Kenya. The Upper unit is represented by the Mazeras Sandstone and Shimba Grits overlain by the Mariakani Sandstones, whereas the Lower, the Majiya Chumvi Beds, are chiefly composed of sands. North-east of the country the Triassic is represented by the Mansa Guda formation, an unfossiliferous sequence of sandstones, conglomerates and quartzites.

The Jurassic ranges from Bajocian to Kimmeridgian and consist of shales, sandstones with intercalations of limestone in the south-east, whereas in the north-east it is chiefly limestone of Lias-Tithonian age. It is not directly correlatable with the Jurassic sediments in the south-east – an evidence for the lack of physical connection between the two basins in Mesozoic times.

The widest outcrop of the Cretaceous occurs in north-eastern Kenya, where a lower series of siltstones and flaggy, fine-grained sandstones are overlain by a thick formation of cross-bedded sandstones, both of which are together known as Marihan Series. In south-eastern Kenya, the Cretaceous is represented by one member, the Freretown Limestone.

1.4 Cenozoic Rocks

The Tertiary Period was marked by marine and deltaic sedimentation. Miocene members occur near Malindi and they are composed of limestones, marls, clays and sands, overlain by Pliocene sands, gravels and clays. Farther inland, Miocene sedimentation is represented by shallow water lacustrine and fluviatile sediments intercalated with thin limestone. Extensive vulcanism occurred in middle and late Tertiary time in central, western, and northern Kenya. Mainly alkaline volcanics: basalts, phonolites, nephelinites, trachytes and their pyroclastic equivalents, were extruded over these areas. Eruptions were of vent or fissure types and in the rift zone, there is evidence that the main fissure eruption occurred before fracturing, which produced the present day fault scarps, whereas the two activities were contemporaneous in other areas.

Volcanic activity which began during middle Tertiary continued to the Pleistocene and Recent when similar rocks were extruded. These consist of raised corals, reefs and sands. Farther inland, particularly in the Rift Valley areas, lacustrine and fluviatile deposits, especially diatomite beds, were deposited, whereas soils and alluvial sediments comprise Recent deposition in eastern Kenya.

1.5 Tectonism

Mountain building, chiefly folding and faulting, began during the Precambrian or early Cambrian and continued until Tertiary times, with varying degrees of intensity. Movements consisted mainly of uplifts with long periods of almost continued denudation, leading to peneplanation of much of Kenya in later Jurassic times. During Cretaceous and early Tertiary, vertical and tilting movements were dominant and their effects are most readily evident along the coast as well as the Rift Valleys.

APPENDIX E

Computer Listings of Borehole Data

BOREHOLE DATA SORTED ACCORDING TO BOREHOLE NUMBERS

20/ 7/1972 WATER BOREHOLE STATISTICS IN KENYA

BOREHOLE REF.NO	DIST	LONG	LAT	DEPTH	WATER STRUCK LEVEL	ELEV	WATER REST LEVEL	ELEV WATER TABLE	TESTED YIELD	DRAW DOWN	YIELD/ DRAW DOWN	ROCK	QUAL	COMPLETION DATE MM	COMPLETION DATE YY	WAS SUBSIDY PAID	ELEV WATER LEVEL
41027	76	35.05'E	0.29'S	107	82	1874	79	1792	8190	0	0	1	1	1	50	3	1795
41028	76	36.01'E	0.19'S	229	225	1905	167	1682	6634	0	0	1	1	1	50	3	1738
41029	24	36.35'E	0.40'S	137	0	2476	0	2476	0	0	0	1	9	12	50	2	2476
41030	24	36.20'E	0.18'S	72	70	0	0	-70	945	0	0	1	9	12	50	2	0
41031	75	36.30'E	0.00'S	127	49	2652	0	2603	0	0	0	1	9	12	50	2	2652
41032	76	36.19'E	0.20'S	18	16	2499	0	2483	0	0	0	1	9	12	50	2	2499
41033	76	35.40'E	0.18'S	163	61	2423	34	2362	12576	0	0	1	1	2	50	3	2389
41034	10	36.51'E	1.15'S	138	79	1630	52	1551	11575	0	0	1	1	1	50	3	1598
41035	31	39.25'E	3.45'S	155	116	213	13	97	10670	0	0	3	2	2	50	3	200
41036	76	35.56'E	0.08'S	186	159	1791	158	1632	0	0	0	1	9	2	50	2	1633
41037	44	37.13'E	1.29'S	153	128	1600	12	1472	2730	115	23	2	1	2	50	3	1586
41038	10	36.41'E	1.19'S	56	40	1817	38	1777	2730	0	0	1	1	1	50	3	1779
41039	21	36.48'E	1.09'S	25	40	1765	46	1725	6825	0	0	1	1	2	50	3	1719
41040	76	35.54'E	0.09'S	155	130	1838	120	1708	8154	0	0	1	9	3	50	3	1718
41041	31	39.57'E	3.05'S	45	0	61	11	61	2730	0	0	3	1	2	50	3	50
41042	31	39.51'E	3.04'S	12	0	34	0	34	0	0	0	3	9	1	50	3	34
41043	76	36.22'E	0.24'S	214	137	2303	0	2166	546	0	0	1	1	3	50	2	2303
41044	63	35.29'E	0.48'N	91	43	2286	33	2243	8395	0	0	2	1	3	50	3	2253
41045	21	37.07'E	1.12'S	61	38	1463	30	1425	410	0	0	5	9	11	48	2	1433
41046	31	39.40'E	3.49'S	38	31	30	9	-1	6006	0	0	3	2	2	50	3	21
41047	31	39.39'E	3.48'S	155	143	244	6	101	5005	0	0	3	1	2	50	3	238
41048	31	39.40'E	3.47'S	153	37	168	3	131	6088	0	0	3	1	3	50	3	165
41049	10	36.59'E	1.16'S	83	43	1722	31	1679	5460	0	0	1	1	10	48	3	1691
41050	10	36.43'E	1.20'S	123	118	1868	85	1750	5913	0	0	1	1	3	50	3	1783

Note: Codings of the data are presented on pages 4 to 8

BOREHOLE DATA SORTED ACCORDING TO LONGITUDE

BOREHOLE REF.NO	DIST	LONG	LAT	DEPTH	WATER STRUCK LEVEL	ELEV	WATER REST LEVEL	ELEV WATER TABLE	TESTED YIELD	DRAW DOWN	YIELD/ DRAW DOWN	ROCK	QUAL	COMPLETION DATE MM	COMPLETION DATE YY	WAS SUBSIDY PAID	ELEV WATER LEVEL
40527	76	35.55'E	0.22'S	137	137	2286	35	2149	11148	0	0	1	1	10	44	3	2251
40062	76	35.55'E	0.13'S	142	0	1975	0	1975	0	0	0	1	9	12	34	2	1975
40202	76	35.55'E	0.22'S	137	133	2316	38	2185	9100	0	0	1	1	11	42	3	2278
40225	76	35.55'E	0.19'S	187	174	2408	101	2234	6552	0	0	1	1	5	43	3	2307
40148	76	35.55'E	0.04'N	77	0	1615	27	1615	410	0	0	1	1	6	41	2	1588
40666	76	35.55'E	0.10'S	158	153	1872	131	1719	5915	0	0	1	1	5	48	3	1741
40765	76	35.55'E	0.22'S	183	136	2240	96	2104	1897	0	0	1	0	11	48	3	2144
40605	76	35.55'E	0.14'S	183	161	2015	156	1854	5915	0	0	1	1	2	49	3	1859
40711	76	35.55'E	0.02'S	142	139	1646	47	1507	5460	0	0	1	1	7	48	3	1599
40641	76	35.55'E	0.09'S	124	121	1824	103	1703	5005	0	0	1	1	2	48	3	1721
41939	70	35.55'E	1.13'S	108	107	1585	62	1478	4095	33	124	1	1	3	53	3	1523
42535	76	35.55'E	0.10'S	19	16	1890	16	1874	11830	0	0	1	0	6	56	3	1876
43243	76	35.55'E	0.22'S	189	177	2273	68	2096	10920	21	520	1	1	6	63	3	2205
43490	76	35.55'E	0.22'S	194	189	2286	107	2097	7849	0	0	1	1	5	68	3	2179
41585	76	35.55'E	0.23'S	167	178	2179	43	2001	10693	48	222	7	1	11	51	3	2136
41749	76	35.55'E	0.22'S	175	134	2271	85	2137	5460	0	0	1	9	4	52	3	2186
41506	76	35.55'E	0.29'S	122	110	2484	7	2374	4095	0	0	1	1	2	51	3	2477
41059	76	35.55'E	0.16'S	244	0	2149	0	2149	0	0	0	1	9	5	50	2	2149
40220	76	35.56'E	0.24'S	153	143	2301	34	2158	8190	0	0	1	1	4	43	3	2267
40211	76	35.56'E	0.21'S	135	93	2179	90	2086	1820	0	0	1	1	2	43	3	2089
40205	76	35.56'E	0.20'S	140	116	2109	104	1993	683	0	0	1	1	12	42	3	2005
40826	76	35.56'E	0.12'S	244	0	1944	0	1944	0	0	0	1	9	3	49	2	1944
40640	76	35.56'E	0.07'S	184	0	1737	0	1737	0	0	0	1	9	6	48	2	1737
41934	76	35.56'E	0.20'S	198	195	2167	97	1972	2594	61	42	1	1	1	53	3	2070
42619	76	35.56'E	0.22'S	159	128	2561	80	2433	6825	36	189	1	1	12	56	3	2481

BOREHOLE DATA SORTED ACCORDING TO LATITUDE

BOREHOLE REF.NO	DIST	LONG	LAT	DEPTH	WATER STRUCK LEVEL	ELEV	WATER REST LEVEL	ELEV WATER TABLE	TESTED YIELD	DRAW DOWN	YIELD/ DRAW DOWN	ROCK	QUAL	COMPLETION DATE MM	COMPLETION DATE YY	WAS SUBSIDY PAID	ELEV WATER LEVEL
41322	63	35.27'E	0.20'N	71	60	2438	5	2376	475	0	0	1	9	10	50	2	2433
43067	75	36.24'E	0.20'S	0	79	2303	61	2224	4550	0	0	1	1	0	0	3	2242
40329	76	35.46'E	0.20'S	97	88	2438	7	2350	10010	0	0	1	1	11	44	3	2431
40336	25	36.45'E	0.20'S	50	27	2355	27	2328	3790	0	0	1	1	2	45	3	2328
40307	76	36.04'E	0.20'S	70	14	1791	13	1777	10465	0	0	1	9	8	44	3	1778
40306	76	36.04'E	0.20'S	73	73	1789	19	1716	13650	0	0	1	1	6	44	3	1770
40205	76	35.56'E	0.20'S	140	116	2109	10?	1993	683	0	0	1	1	12	42	3	2005
40042	75	36.35'E	0.20'S	85	75	1920	34	1845	4914	0	0	1	1	12	38	3	1886
40744	24	36.24'E	0.20'S	76	0	1951	0	1951	0	0	0	1	9	10	48	2	1951
40813	76	36.11'E	0.20'S	153	146	1898	121	1752	9478	0	0	1	1	3	49	3	1777
40790	25	36.55'E	0.20'S	76	49	1928	48	1879	1274	0	0	1	1	12	48	3	1880
40747	25	36.55'E	0.20'S	183	55	1910	40	1855	2048	0	0	1	1	11	48	3	1870
40748	25	36.56'E	0.20'S	37	13	1829	0	1816	4095	0	0	1	1	11	48	3	1829
42039	24	36.16'E	0.20'S	183	0	2438	0	2438	0	0	0	1	9	10	53	2	2438
42270	46	37.39'E	0.20'S	156	145	1341	61	1196	6689	61	109	1	1	10	54	3	1280
41934	76	35.56'E	0.20'S	198	195	2167	97	1972	2594	61	42	1	1	1	53	3	2070
41935	76	35.57'E	0.20'S	184	128	2164	122	2036	6825	11	620	1	1	3	53	3	2042
42210	76	36.14'E	0.20'S	143	137	1966	52	1829	10010	15	667	1	1	5	54	3	1914
42377	25	36.57'E	0.20'S	109	98	1882	44	1784	4004	35	114	1	9	4	55	3	1838
43559	76	35.58'E	0.20'S	199	195	2145	104	1950	4550	45	101	1	1	4	69	3	2041
43467	76	35.58'E	0.20'S	229	0	2243	0	2243	0	70	0	1	9	11	67	2	2243
43627	76	35.58'E	0.20'S	138	125	2143	100	2018	9100	19	478	1	9	7	69	3	2043
43375	10	36.49'E	0.20'S	106	0	1609	98	1609	2275	0	0	1	9	0	0	3	1511
41327	75	36.59'E	0.20'S	126	122	1981	63	1859	8154	0	0	1	1	9	51	3	1918
41491	76	35.56'E	0.20'S	162	151	2118	83	1967	10351	0	0	1	1	7	51	3	2035
[illegible]	76	36.55'E	0.20'S	56	24	[illegible]	19	[illegible]	18964	0	0	1	2	7	51	3	1770

Coding of Borehole Data

The following data is included in the borehole statistics:-

Borehole Number

There are three series of boreholes, numbered as follows:

(i) The "SA" Series, which is boreholes drilled by the South African Army during the Second World War. There is a total of 133 boreholes with the prefix "SA". On the computer print-outs these boreholes are identified as 00001 to 00133.

(ii) The "P" Series, being boreholes drilled before 1933. There are 190 boreholes of this Series which are identified as 10001 to 10190 on the print-outs.

(iii) The "C" Series, which started in 1933 and includes close to 4 000 boreholes. The borehole numbers in this Series are coded as 40001-

District

A two-digit code is given for the district in which the borehole is located. The codes are as follows:

Province	District	Code
NAIROBI	Nairobi	10
CENTRAL PROVINCE		20
	Kiambu	21
	Kirinyaga	22
	Muranga	23
	Nyandarua	24
	Nyeri	25
COAST PROVINCE		30
	Kilifi	31
	Kwale	32
	Lamu	33
	Mombasa Island	34
	Taita	35
	Tana River	36

Province	District	Code
EASTERN PROVINCE		40
	Embu	41
	Isiolo	42
	Kitui	43
	Machakos	44
	Marsabit	45
	Meru	46
NORTH-EASTERN PROVINCE		50
	Garissa	51
	Mandera	52
	Wajir	53
NYANZA PROVINCE		60
	Kisii	61
	Kisumu	62
	Siaya	63
	South Nyanza	64
RIFT VALLEY PROVINCE		70
	Baringo	71
	Elgeyo Markwet	72
	Kajiado	73
	Kericho	74
	Laikipia	75
	Nakuru	76
	Nandi	77
	Narok	78
	Samburu	79
	Trans-Nzoia	81
	Turkana	82
	Uasin Gishu	83
	West Pokot	84
WESTERN PROVINCE		90
	Bungoma	91
	Busia	92
	Kakamega	93

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Longitude

The map reference in longitude to the nearest minute (1' - about 2 km) is given on the print-out.

Latitude

The latitude to the nearest minute is given.

Depth

Depth of boreholes is given in metres.

Water Struck Level

Water struck level is given in metres.

Elevation

The ground-level at boreholes is given in metres above mean sea-level. The elevation has not been surveyed. It is estimated from contour maps.

Water Rest Level

The static water level is expressed in metres.

Elevation of Water Struck Level

The elevation of the water table is given in metres above mean sea-level.

Tested Yield

The tested yield is expressed in litres per hour. It should be noted that the test pumping is of relatively short duration and does not usually, therefore, represent the maximum capacity of the borehole. The tested yield can sometimes be higher than the maximum yield as the depletion cone does not become fully developed. In other cases, the pump is the limiting factor, rather than the yield of the borehole.

Draw Down

Draw down is defined as the fall in the water head resulting from pumping. It is the difference between the water rest level just before pumping and during pumping. It is an important factor in the determination of the specific capacity (yield/draw down) of the aquifer.

...7

Yield tests are made after drilling to determine the potential of a borehole and the safe yield. Although data required for calculating the draw down can easily be observed and recorded, this has been done in less than 25 per cent of the borehole records on file.

The draw down is given in metres.

Yield/Draw Down

The specific capacity (yield divided by draw down) is given in litre/hour/metre.

Rock Category

The following categories of rock are coded:

Type	Code
Volcanic	1
Basement	2
Sedimentary	3
Volcanic over basement	4
Sedimentary over basement	5
Sedimentary over volcanic	6
Volcanic over sedimentary	7
Other	8
Not known	9

Water Quality

The water quality has been coded as follows:

Type	Code
Good	1
Saline potable	2
Saline not potable	3
Not known	9

It should be noted that past records are very incomplete. Proper chemical analyses have only been carried out over the last few years.

Completion Date

The completion date of the borehole is given in month (1 = January, 12 = December) and year.

Subsidy

Boreholes sited by WD for agricultural purposes are eligible for subsidy which is an insurance against failure. If a borehole is successful no subsidy is paid. This item is coded as follows:

	Code
No subsidy	0
Subsidy paid	1
Not known whether subsidy paid	2
Not applicable	3

Elevation Water Level

The elevation of the water level is given in metres above mean sea-level.

APPENDIX F

Water Table Statistics

WATER TABLE STATISTICS TABULATED BY DISTRICT

PROVINCE AND DISTRICT	NUMBER OF BOREHOLES	AVERAGE WATER TABLE	VARIANCE	STANDARD DEVIATION
NAIROBI	447	1 632	106 956	327
CENTRAL PROVINCE	927	1 808	99 458	315
KIAMBU	699	1 656	178 534	423
KIRINYAGA	2	1 188	5	2
MURANGA	73	1 376	69 420	263
NYANDARUA	115	2 293	203 529	451
NYERI	38	1 896	74 961	274
COAST PROVINCE	281	735	688 154	830
KILIFI	132	59	34 732	186
KWALE	41	301	76 454	277
LAMU	6	25	531	23
MOMBASA	46	120	59 704	244
TAITA	48	727	198 993	446
TANA RIVER	8	596	506 915	712
EASTERN PROVINCE	510	958	140 733	375
EMBU	7	1 169	23 762	154
ISIOLO	20	827	222 105	471
KITUI	36	1 040	72 348	269
MACHAKOS	391	1 397	141 912	377
MARSABIT	31	700	134 079	366
MERU	25	1 729	315 052	561
NORTH EAST PROVINCE	93	715	279 367	529
GARISSA	37	89	44 060	210
MANDERA	15	421	64 934	255
WAJIR	41	317	145 581	382
NYANZA PROVINCE	93	871	269 482	519
KISII	4	1 225	698 188	836
KISUMU	63	1 270	63 873	253
SIAYA	3	955	296 862	545
S. NYANZA	23	1 238	92 555	304
RIFT VALLEY PROVINCE	1 233	1 451	492 784	702
BARINGO	18	1 584	343 465	586
ELGEYO MKT	5	939	54 469	233
KAJIADO	115	1 578	67 704	260
KERICHO	63	1 745	293 614	542
LAIKIPIA	204	1 843	145 820	382
NAKURU	590	2 004	165 387	407
NANDI	1	2 134	0	0
NAROK	5	1 615	902 795	950
SAMBURU	31	1 232	346 881	589
TRANS NZOIA	41	1 123	469 963	686
TURKANA	31	810	579 736	761
UASIN GISHU	121	1 177	651 052	807
WEST POKOT	8	1 904	654 504	809
WESTERN PROVINCE	23	1 326	0	0
BUNGOMA	8	546	110 738	333
BUSIA	9	730	228 730	478
KAKAMEGA	6	1 031	408 874	639
TOTAL	3 607	1 482	451 802	672

APPENDIX G

Major Borehole Statistics Tabulated
According to Rock Type

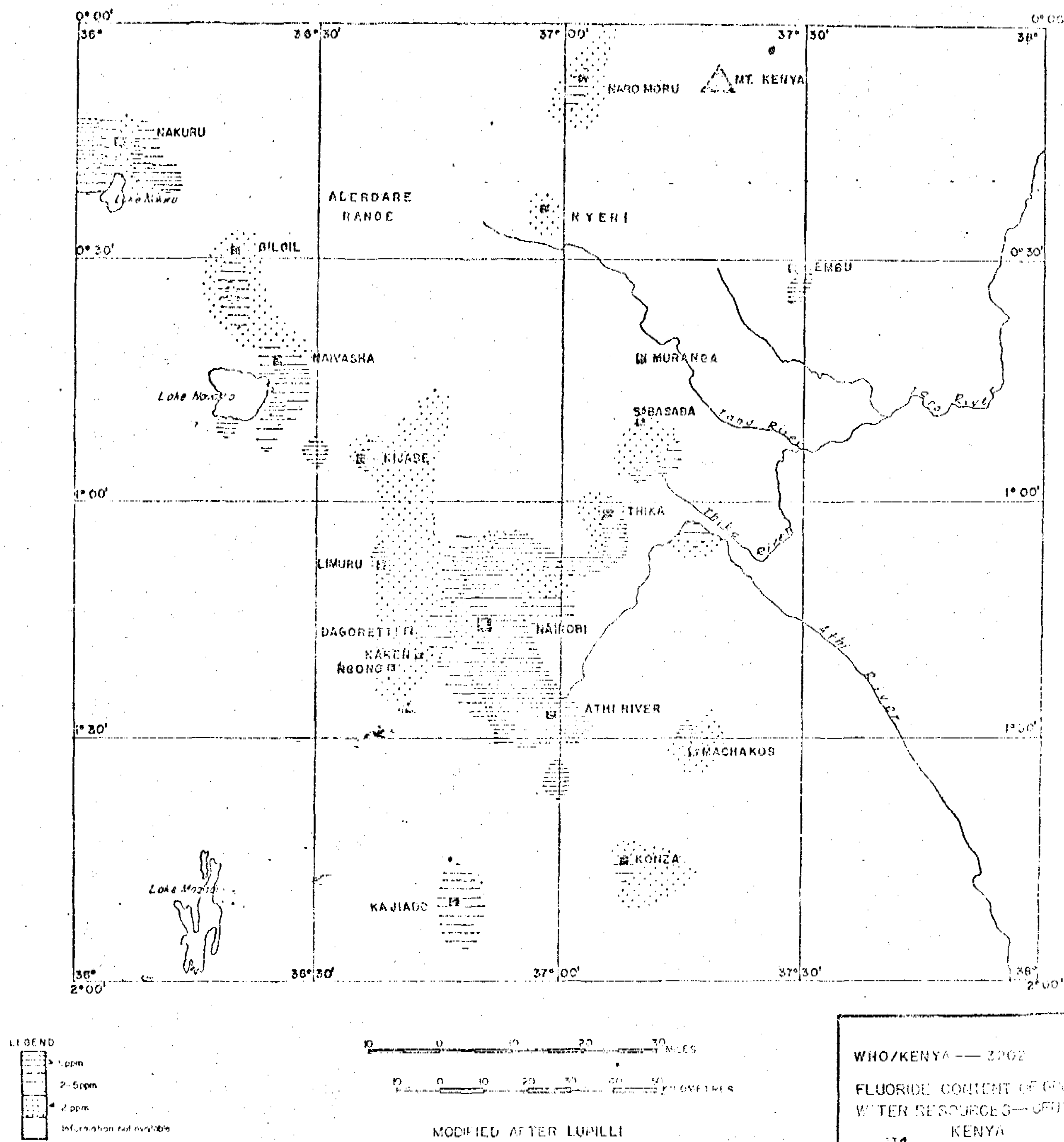
APPENDIX G

MAJOR BOREHOLE STATISTICS TABULATED ACCORDING TO ROCK TYPE

ROCK TYPE	VOLCANIC ROCKS	SEDIMENTARY ROCKS	BASEMENT ROCKS	OTHERS	TOTAL
Number of boreholes	2 500	356	724	35	3 639
Average depth (m)	127	77	89	105	114
Standard deviation	63	61	54	49	64
Number of boreholes	2 327	304	605	33	3 291
Average yield (m^3/Hr)	7.4	6.1	4.6	4.4	6.7
Standard deviation	7.1	6.8	6.0	5.4	7.0
Number of boreholes	851	80	227	9	1 177
Average specific capacity (m^3/Hr/m)	0.8	2.4	0.5	0.3	0.9
Standard deviation	2.1	4.4	1.4	0.5	2.3

APPENDIX H

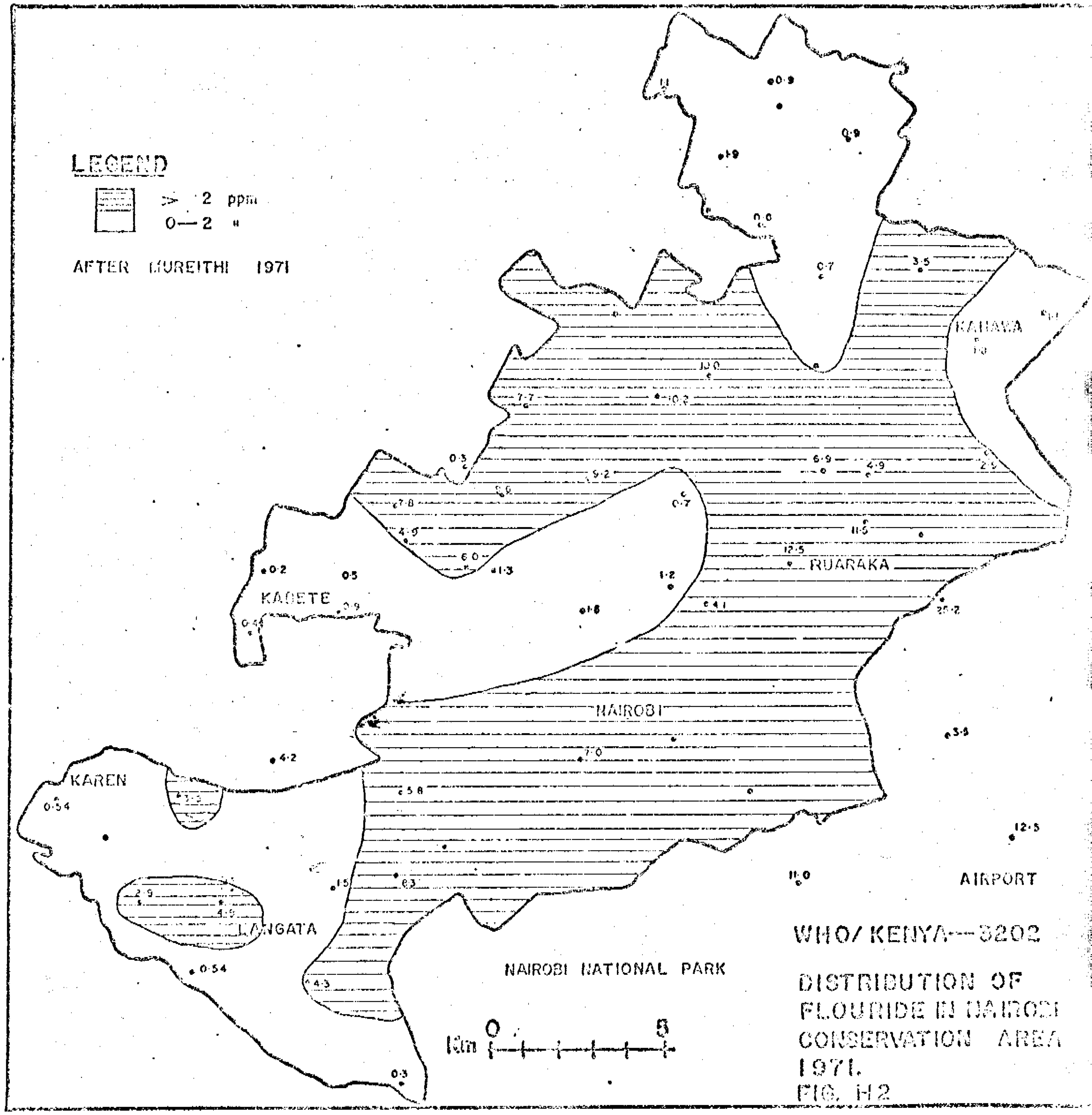
Distribution of Fluoride



WHO/KENYA — 3202

FLUORIDE CONTENT OF GROUND WATER RESOURCES— CENTRAL KENYA

H1



WHO/ KENYA—3202

DISTRIBUTION OF FLOURIDE IN NAIROBI CONSERVATION AREA 1971.

FIG. H2

APPENDIX I

Chemical Composition of Groundwater
in the North Eastern Province

CHEMICAL COMPOSITION OF GROUNDWATER, NE PROVINCE, KENYA

[illegible]EHOLE	T.D.S.	HCO_3	CO_3	SO_4	NO_3	NO_2	F	Ca	K	Mg	HARDNESS CO_3	TOTAL HARDNESS	Na	Cl	Na/Cl	Cl/(HCO_3+CO_3)
570	4 050	–	–	646	N	N	0.3	186	–	–	120	1 100	–	1 768	–	–
571	3 196	170	–	496	–	–	0.3	152	–	122	170	883	–	1 350	–	8
616	4 070	414	–	646	P	P	1.0	314	–	255	414	1 840	–	1 472		3.5
645	15 060	164	–	1 415	H	H	1.2	495	–	501	164	3 299	–	8 170	–	5
687	2 230	1 095	–	1 576	H	H	9.4	–	–	–	–	80	–	11 400		14
618	35 305	498	–	2 452	N	P	15.2	315	–	437	498	2 579	–	11 940	–	24
636	10 560	2 536	704	1 633	13	1.0	2.0	50	13	N	66	66	3 600	3 100	1.16	0.92
654	720	572	28	22	0.1	0.01	0.7	26	8	31	194	194	174	76	2	0.12
719	25 900	–	–	2 432	1.5	–	3.3	392	–	–	475	2 800	–	1 290		
033	6 910	–	–	671	3.6	0.35	2.3	22	–	–	390	390	–	3 180		
038	12 735	–	–	2 129	–	–	1.1	126	–	–	650	985	–	5 500		
041	11 [illegible]	–	–	572	0.6	0.09	1.8	428	–	–	130	2 970	–	6 080		
070	[illegible]	–	–	1 355	–	–	1.6	214	–	164	205	1 210	–	4 410		
527	4 250	–	–	76	–	–	0.6	135	–	–	–	2 380	–	2 165		
549	150	674	–	75	–	0.01	1.5	335	–	40	39	335	–	176		0.26
568	2 100	–	–	650	T	T	1.6	350	–	65	256	1 108	–	1 150		
224	15 540	–	–	3 912	0.5	L.E. 0.01	3.2	852	78	535	360	4 320	3 927	5 900	0.66	
207	4 870	–	–	816	0.03	0.01	0.3	189	30	188	115	1 255	1 180	2 050	0.57	
306	3 750	–	–	73	38	0.06	1.3	309	44	118	170	1 235	860	2 010	0.43	
569	2 808	212	–	323	50	0.02	2	170	19	145	212	1 030	475	1 060	0.45	9.7
571	2 992	196	–	533	0.1	T	1.0	213	40	209	196	1 401	470	1 360	0.35	6.[illegible]
572	2 [illegible]	312	–	440	2.3	0.04	1.0	98	[illegible]	164	312	927	590	1 080	0.55	[illegible].5
[illegible]	1 700	404	–	263	8.[illegible]	0.1	1.7	264	15	81.5	404	1 012	190	510	0.37	1.3

3 592	5 776	-	--	1 440	-	-	-	-	-	-	-	-	-	1 880	-	-
3 628	10 430	-	-	1 872	-	-	-	-	-	-	4 827	-	-	4 120	-	-
2 685 / 2 685	805	543	25	N	P	1.8	-	-	-	-	-	40	-	-	-	-
3 085	1 040	-	-	107	N	N	2.0	..	..	-	80	80			-	
100	1 407		-	126	T	P	-	..	-	-	5	135	-	135	-	
103	12 840	-	-	1 722	T	L.A.	-	-	..	2.54	-	-	..	3 780	-	
2 485	720	385	-	25	P	T	0.7	-	-	-	-	60	-	94	-	0.2
3 085	1 040	-	-	107	N	T	2.0	..	..	-	80	80	-	164	-	
3 120	1 200	-		499	N	N	2.5	157	1	62	230	650T	-	122	-	
3 155	2 940	-		165	20	0.06	1.2	232	-	188	270	1 350	-	980	-	
3 218	765	-	-	66	0.4	0.01	1.0	27	..	-	210	210	220	88	2.5	
3 240	380	-	-	25	N	N	0.5	16	9	10	80	80	118	28	4.2	
3 406	882	540	-	-	N	N	1.7	6	14	-	59	59	324	98	3.3	0.3
3 527	425	-	-	76	-	-	0.6	135	-			2 380	-	2 165	-	
3 540	-	-	-	-			1.6				204	-	-	25	-	
3 635	466	306	-	60	N	N	1	56	8	14	200	200	70	50	1.4	0.16
3 655	795	480	-	46.7	0.5	0.01	2.3	30.5	13	17	148	148	184	100	1.84	0.21
3 656	472	300	-	-	5	0.1	-	15	10	57	276	270	30	18	1.7	0.04
3 657	870	374	-	89	1.75	0.01	3.64	60.5	4	0.01	324	324	120	144	0.8	0.5
3 658	764	340	-	88	0.75	0.01	1.62	30.5	4	34	296	296	100	120	0.8	0.35
3 667	716	324	-	51	1.12	0.01	1.18	58	15	46	324	356	62	140	0.4	0.43
3 684	1 175	320	-	39	15.1	0.01	0.54	70.4	20	62.5	320	436	240	336	0.7	0.98
3 685	920	430	-	105	5.0	0.01	1.6	19	20	25	152	152	320	109	3	0.2
3 687	1 020	320	-	42.7	0.13	N	0.4	21.5	10.5	7.0	83	85	96	34	3	0.11
3 695	-	476	-	41	5.0	0.05	0.7	34	14	29	206	200	80	38	2	0.07
3 697	-	854	-	87	2.7	0.05	2.2	10	4.5	46	214	214	520	150	3	0.17

APPENDIX K

Chemical Composition of Water in the Coastal Areas

CHEMICAL COMPOSITION OF WATER IN THE COASTAL AREAS

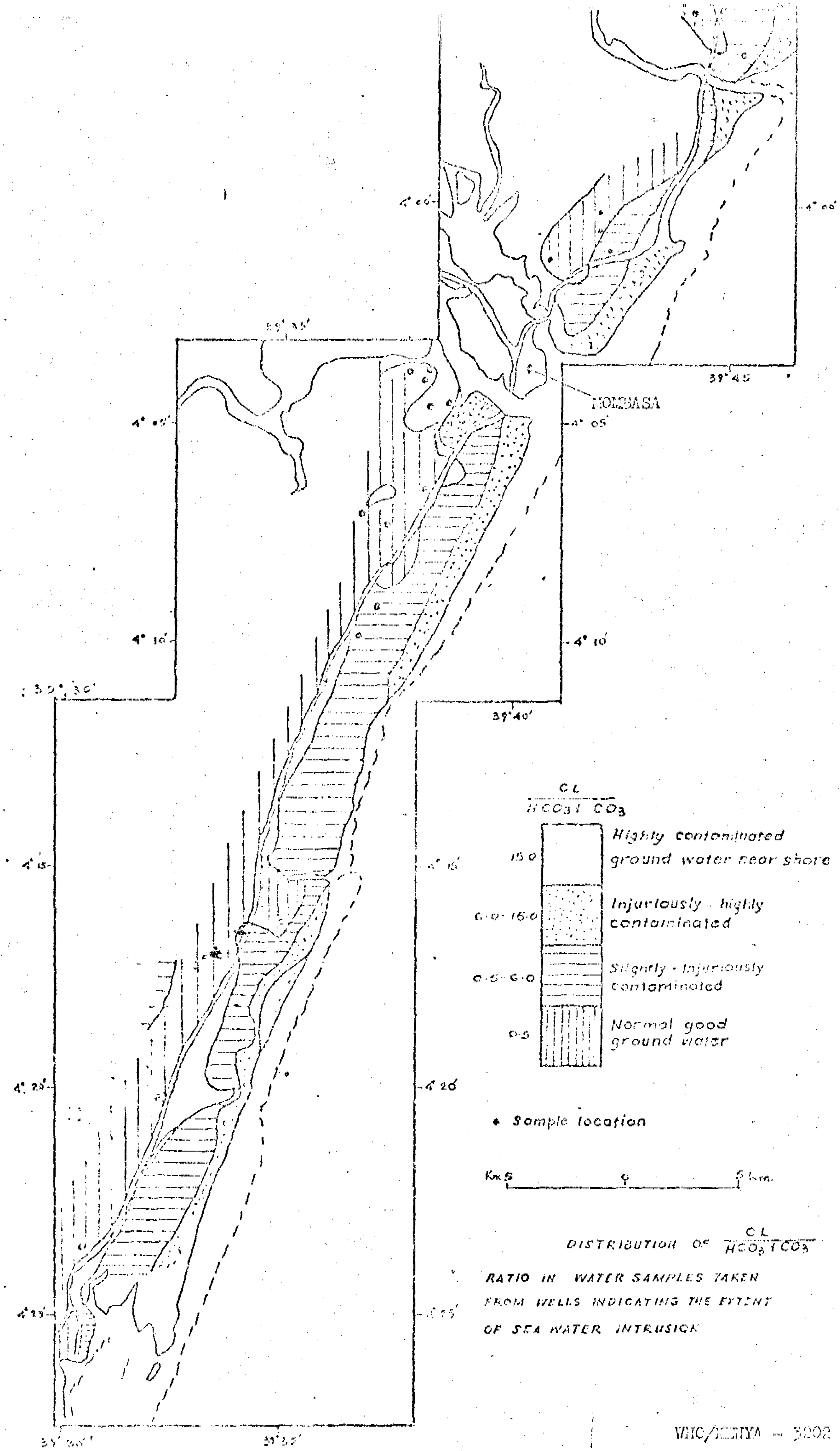
(SAMPLES COLLECTED 14-16 JUNE 1972)
All figures in ppm

LOCATION	Sodium Na	POTASSIUM K	CALCIUM Ca	MAGNESIUM Mg	IRON Fe	AMMONIUM NH_4	HEAVY METALS (Pb, Cu, Zn)	CATIONS	HARDNESS CARBONATE ($CaCO_3$)	HARDNESS NON-CARBONATE ($CaCO_3$)	TOTAL HARDNESS ($CaCO_3$)	T.D.S. Residue dried at 180°C	TOTAL DISSOLVED SOLIDS after ignition	BICARBONATE HCO_3	CARBONATE CO_3	CHLORIDE Cl	SULPHATE SO_4	NITRATE NO_3	NITRITE NO_2	FLUORIDE F	ANIONS	FREE CO_2	SiO_2	ABSORBED CO_2
MAYFAIR FARM	424	8	134	42	0.1	0.3	NOT DETECTED	608	224	204	510	1 880	1 625	273	NIL	805	147	2.0	1.3	0.4	1 229	27	30	1.9
MAYFAIR FARM	336	25	152	32	0.2	NIL	N.D.	596	280	234	514	1 850	1 680	342	NIL	785	140	0.6	0.03	0.8	1 259	12	30	0.6
GANDA	131	8	101	27	0.1	NIL	N.D.	267	260	106	366	800	640	317	NIL	224	60	5.5	0.01	0.4	607	20	45	0.2
GANDA	140	9	98	23	0.4	NIL	N.D.	270	338	NIL	338	725	560	412	NIL	180	47	1.8	NIL	0.5	642	30	40	0.2
GANDA	147	3	98	23	0.8	0.1	N.D.	278	338	NIL	330	780	620	473	NIL	180	51	3.1	0.01	0.3	707	37	35	0.2
MTODIA	200	21	115	46	0.2	0.1	N.D.	382	296	184	480	950	750	361	NIL	380	45	8.9	0.03	0.4	795	14	35	0.4
KIBARANI	688	36	328	533	0.2	NIL	N.D.	1 535	160	2 880	3 040	6 610	5 170	195	NIL	3 900	653	NIL	0.01	0.6	4 749	4	25	0.2
NEAR KIBARANI	274	16	147	80	0.2	0.1	N.D.	517	316	384	700	1 530	1 185	386	NIL	645	100	6.1	0.07	0.4	1 137	22	20	0.1
KIKAMBALA	50	5	70	28	0.2	0.1	N.D.	153	252	40	292	415	300	307	NIL	75	31	1.6	NIL	0.6	416	12	20	0.3
DENYENJE	32	3	92	8	0.1	0.1	N.D.	135	256	8	264	360	265	312	NIL	30	7	8.9	NIL	0.2	358	10	20	0.3
GAZI	32	5	118	12	0.2	0.1	N.D.	167	332	12	344	460	420	405	NIL	30	14	4.4	0.01	0.1	453	25	20	0.1
MSAMBWENI	33	15	110	14	0.6	NIL	N.D.	173	232	104	336	435	315	283	NIL	50	41	39.9	0.01	0.4	414	15	20	0.1
MSAMBWENI	18	3	83	16	0.1	0.1	N.D.	121	276	NIL	276	360	250	351	NIL	15	13	2.2	NIL	0.7	382	14	20	0.2
MSAMBWENI	23	3	32	17	0.2	0.04	N.D.	75	130	20	150	220	200	159	NIL	40	12	0.6	NIL	0.3	212	22	25	0.2
SEA-WATER	9 360	392	404	1 462	0.2	0.3	N.D.	12 218	144	6 956	7 100	35 960	33 335	176	NIL	9 000	2 056	NIL	0.01	0.2	21 232	4	3	1.0

APPENDIX K

APPENDIX L

Water Quality Maps - Coastal Area

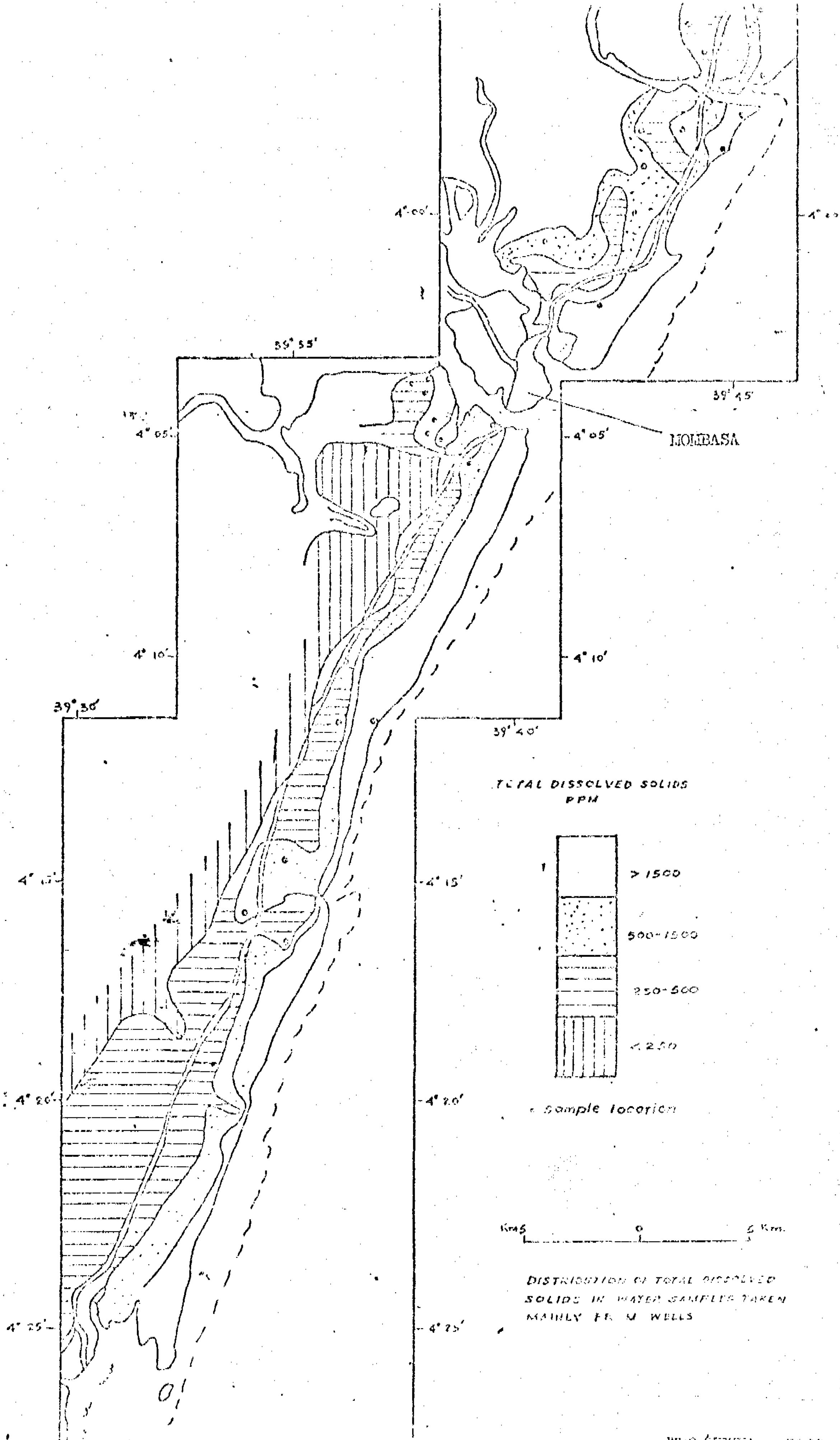


Modified after Gauble

WHO/KENYA - 3202

DISTRIBUTION OF
$cl/(HCO_3 + CO_3)$
ratio

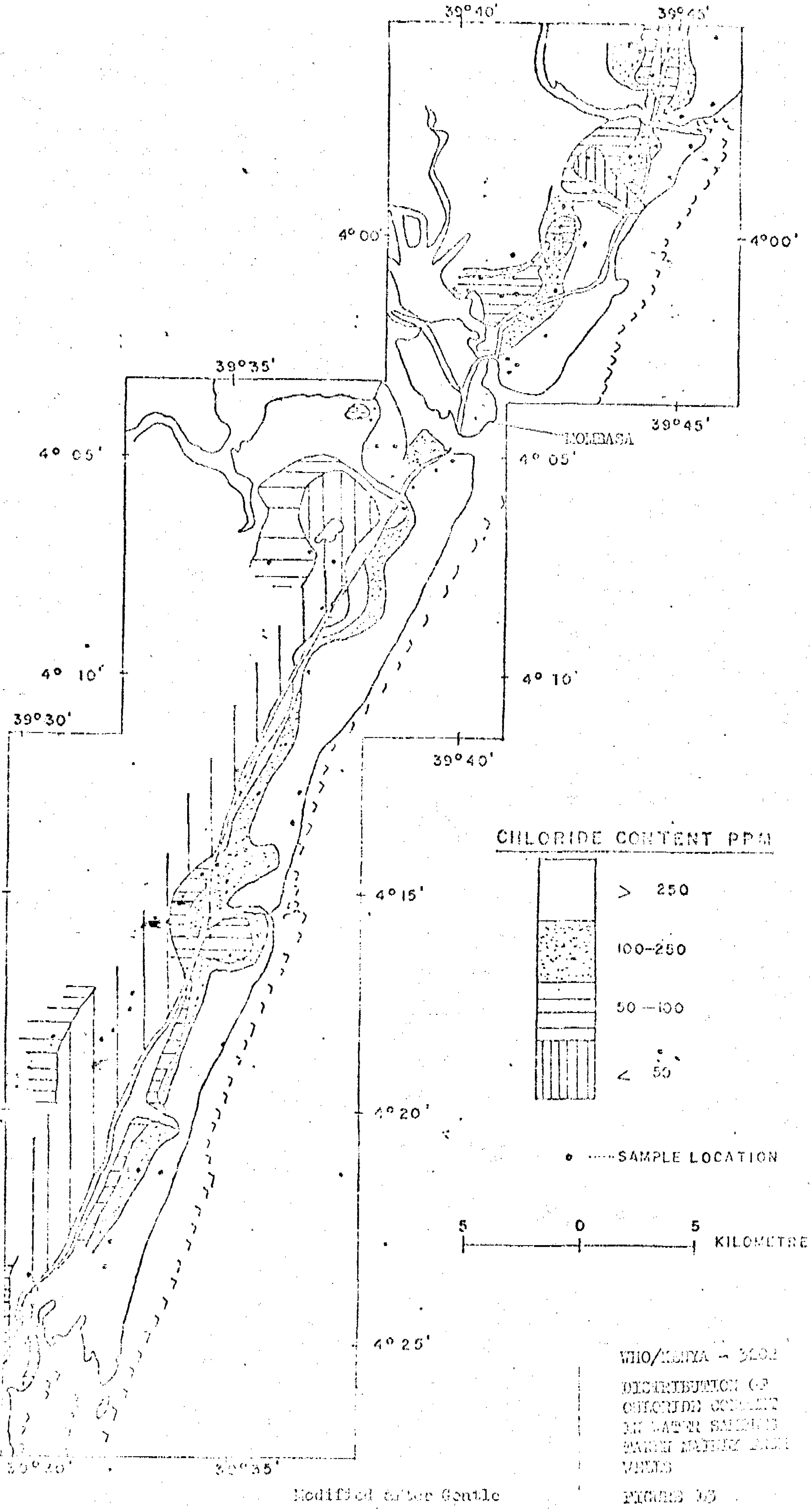
FIGURE 16



WHO/KENYA

TOTAL DISSOLVED SOLIDS

Modified after Gentle



Modified after Gentle

WHO/KENYA - 3202

DISTRIBUTION OF CHLORIDE [illegible] IN WATER [illegible] [illegible] [illegible] [illegible] WELLS

FIGURE 33

APPENDIX M

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APPENDIX N

Sectorial Study Reports

APPENDIX N

LIST OF WHO SECTORIAL STUDY REPORTS

REPORT NO	REPORT TITLE
1	General Community Water Supply Problems
2	Recommendations on National Programme for Community Water Supply Development
3	Current Sewage Disposal Methods and Problems
4	Design and Selection Criteria for Community Water Supplies
5	Water Pollution Control
6	Water Legislation
7	GROUNDWATER RESOURCES IN KENYA
8	Recommendations on a National Programme for Sewage Disposal
9	Design and Selection Criteria for Sewerage Projects
10	Recommendations on Administration and Organizational Structure for Water Supply and Sewerage Development
11	Manpower and Training Requirements
12	Proposed 10 Year Development Programme for Community Water Supply
13	Proposed 10 Year Development Programme for Sewerage Development
14	Preliminary Design of Ngariama Water Supply
15	Preliminary Design of Ngong Sewerage Scheme
16	Surface Water Resources in Kenya
17	Final Report