REPUBLIC OF KENYA

MINISTRY OF WATER DEVELOPMENT

MERU

WATER RESOURCES ASSESSMENT STUDY

MAIN REPORT

June 1991

WATER RESOURCES
ASSESSMENT SECTION
NAIROBI, KENYA

WRAP
WATER RESOURCES
ASSESSMENT & PLANNING

TNO – INSTITUTE
OF APPLIED GEOSCIENCE
DELFT, THE NETHERLANDS

PREFACE

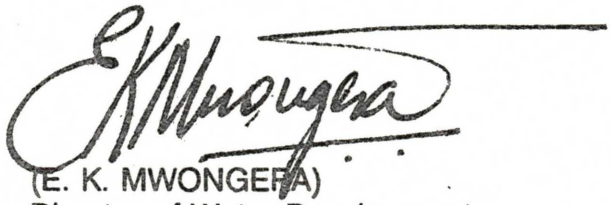
It gives me great pleasure to introduce the District Water Development Study for Meru District.

The Ministry of Water Development has the task of planning for water resources development, both at national and district levels. Districts have been assigned a major role in the development of the country as illustrated by the District Focus Strategy for Rural Development Policy. Consistent with this policy the Ministry of Water Development has put great emphasis on the studies for District Water Development Planning.

Water resources development can only be successfully undertaken if the long-term planning reflects the balance between availability and exploitation of water. Extensive investigations and monitoring are needed to determine the potential of the water resources and the effects of development on long-term basis. Presently, the Districts do not have the research capacity to carry out the necessary studies independently. To overcome this situation, the Ministry of Water Development has established a Water Resources Assessment Section that supports the Districts in carrying out these studies. The Section is being strengthened by the Water Resources Assessment and Planning Project.

The present study provides extensive information on the availability of water resources, the existing supply, the future water demand and the investments involved in developing the water resources in Meru District. Equipped with this information the District will be in a better position to plan its supply facilities. It is only after the District succeeds in explaining to the people the limitations of the natural system and the vulnerability of the environment involving them as much as possible in the planning and construction of their water supplies, that the difficult task of providing water to the people will see a good end.

I express the wish that this important study will be optimally used to achieve this common goal.



(E. K. MWONGERA)
Director of Water Development

TABLE OF CONTENTS

Page

PREFACE i

CONTENTS iii

ABBREVIATIONS viii

SUMMARY ix

1. INTRODUCTION TO THE PROJECT AREA 1

1.1 Location of the District 1
1.2 Physiography 1
1.3 Climate 3
1.4 Drainage System 5
1.5 Soils and Landuse 5
1.6 Population 6
1.7 Livestock 7
1.8 Water Supply and Water Demand Projection 7

2. GEOLOGY 9

2.1 Previous Geological Studies 9
2.2 Geological Setting and History 10
2.3 Stratigraphy 10

2.3.1 Basement System 11
2.3.2 Tertiary Sediments 12
2.3.3 Tertiary Volcanics 12
2.3.3 Quaternary Volcanics 13
2.3.4 Quaternary Sediments 13

2.4 Structures 13

3. GEOPHYSICS 15

3.1 Introduction 15
3.2 Previous Geophysical Studies 15
3.3 Geophysical Fieldwork 16
3.4 Data Processing, Interpretation and Correlation 17
3.5 Results 18

4. HYDROLOGY 23

4.1 Introduction 23
4.2 Previous Studies 23
4.3 Hydrometeorological Network 23
4.4 Rainfall 25

Page

4.4.1 Relation Between Rainfall and Topography 25
4.4.2 Seasonal Rainfall 25
4.4.3 Annual Rainfall 29

4.5 Evaporation 35

4.5.1 Relation Between Evaporation and Topography 35
4.5.2 Monthly Evaporation 35
4.5.3 Comparison of Pan Evaporation, Potential Evaporation and Evapotranspiration 37
4.5.4 Comparison of Mean Monthly Rainfall and Pan Evaporation 38

4.6 Surface Runoff 38

4.6.1 General 38
4.6.2 Ewaso Ng'iro Drainage System 39
4.6.3 The Tana River Drainage System 39

4.7 Streamflow Related to Catchment Size and Precipitation 41

4.7.1 General 41
4.7.2 Available Data 41
4.7.3 Analysis and Results 41

4.8 Baseflow 42
4.9 Surface Water Quality 44

5. HYDROGEOLOGY 47

5.1 Introduction 47
5.2 Previous Hydrogeological Studies 47
5.3 Data Collected and Analysed by WRAP 48

5.3.1 Landsat Data and Aerial Photographs 48
5.3.2 Springs 48
5.3.3 Boreholes 49
5.3.4 Groundwater Levels 51
5.3.5 Pumptests 51
5.3.6 Chemical Data 53

5.4 Groundwater Zones 53

5.4.1 Mount Kenya - Zone I 53
5.4.2 Nyambeni Range - Zone II 57
5.4.3 Volcanic Plains - Zone III 59
5.4.4 Basement Area - Zone IV 60

5.5 Groundwater Level Fluctuations 61
5.6 Groundwater Flow 64

Page

5.6.1 Groundwater Flow Pattern 65
5.6.2 Groundwater Flow Calculations 65
5.6.3 Comparison of Groundwater Flow and Baseflow 67

5.7 Groundwater Quality 68

6. WATER RESOURCES 69

6.1 Introduction 69
6.2 Water Resources Availability 69

6.2.1 Surface Water Availability 69
6.2.2 Groundwater Availability 71

6.3 Water Resources Development Potential 75

6.3.1 Surface Water Development Potential 75
6.3.2 Groundwater Development Potential 75

REFERENCES 77

LIST OF TABLES

		Page
1.1	Land Classification of Meru District	6
1.2	Population Projections 1979 - 1988	6
1.3	Estimated population Densities in 1988 in Meru	7
1.4	Livestock in Meru District	7
1.5	Water sources	8
2.1	Simplified Lithostratigraphic Table of Meru District	11
4.1	Mean Monthly Rainfall Distribution (mm)	27
4.2	Mean Seasonal Rainfall Distribution	28
4.3	Mean Monthly Pan Evaporation Rates in mm	37
4.4	Comparison of Annual Evaporation Rates and Rainfall (mm)	38
4.8	Streamflow related to Drainage Area and Precipitation	42
4.9	Estimates of Hydrography Depletion from Hydrography Analysis	43
5.1	Boreholes Drilled by WRAP	50
5.2	Summary of Groundwater Sub-zones	52
5.3	Borehole yield and Aquifer Lithology in Samburu District	61
5.4	Groundwater Level Monitoring	62
5.5	Groundwater Flow	66
5.6	Suitability of Water for Domestic Use	67
6.1	Summary of streamflow in Meru District	71

LIST OF FIGURES

		Page
1.1	Regional Assessment Studies under the WRAP Programme 1981-1990	0
1.2	Map of Meru District	2
1.3	Landuse, Main Crops and Agroclimatic Zones	4
2.1	Available Geological Reports	9
4.1	Mean Monthly Rainfall Distribution Patterns	26
4.2	Trends of Annual Rainfall	30
4.3	Mean Seasonal Rainfall Distribution (March - May)	32
4.4	Mean Seasonal Rainfall Distribution (Oct.-Dec.)	33
4.5	Mean Annual Rainfall Distribution	34
4.6	Evaporation-Altitude Correlation	36
4.7	Mean Monthly Pan Evaporation	36
4.8	Mean Flow Related to Catchment Size and Mean Rainfall	40
4.9	96% Flow Related to Catchment Size and Mean Rainfall	40
4.10	80% Flow Related to Catchment Size and Mean Rainfall	40
5.1	Condition of Boreholes in Meru District	51
5.2	Hydrogeological Zones	54
5.3	Groundwater Level Fluctuations	63
5.4	Groundwater Level Contours	64
5.5	Groundwater Flow	66
6.1	Streamflow, generated in Meru District, flowing into the Tana River	70
6.2	Streamflow, generated on Mt. Kenya, passing the Chuka Nanyuki Road	70
6.3	Surface Water Availability	72

LIST OF PLATES

2.1 Geological Map

3.1 Depth to the Unweathered Basement

5.1 Hydrogeological Map *(enclosed in Appendices)*

ABBREVIATIONS

ASAL	=	Arid and Semi-Arid Lands Development Program
CBWDP	=	Central Baringo Water Development Plan
CC	=	County Council
DANIDA	=	Danish International Development Agency
DDC	=	District Development Committee
DDP	=	Meru District Development Plan 1989-1993
DvDC	=	Divisional Development Committee
DWDP	=	District Water Development Plan
DWDS	=	District Water Development Study
EEC	=	European Economic Commission
FINNIDA	=	Finnish International Development Agency
GOK	=	Government of Kenya
GSK	=	Groundwater Survey Kenya
GTZ	=	Deutsche Gesellschaft fur Technische Zusammenarbeit
KFRWSDP	=	Kenya Finland Rural Water Supply Development Project in Western Province
KIDP	=	Kitui Development Program
Ksh	=	Kenya shilling
KWAHO	=	Kenya Water for Health Organization
KWDP	=	Kwale District Community Water Supply and Sanitation Project
L.U.	=	Livestock Unit
LBDA	=	Lake Basin Development Authority
lpcd	=	liters per capita per day
MoA	=	Ministry of Agriculture
MOH	=	Ministry of Health
MoLD	=	Ministry of Livestock Development
MoWD	=	Ministry of Water Development
MPND	=	Ministry of Planning and National Development
msl	=	Meters above mean sea level
NGO	=	Non-Government Organization
NORAD	=	Norwegian Agency for Development
ODA	=	Overseas Development Agency
Shs	=	Kenya shilling
SIDA	=	Swedish International Development Agency
UNDP	=	United Nations Development Project
UNICEF	=	United Nations International Childrens Emergency Fund
USAID	=	United States Agency for International Development
WECO	=	Western College of Arts
WRAP	=	Water Resources Assessment and Planning Project

SUMMARY

Water Resources Assessment and Planning Project

The Water Resources Assessment and Planning (WRAP) Project carried out a water resources assessment study in Meru District as part of the co-operation between the Ministry of Water Development, Kenya and TNO-DGV Institute of Applied Geoscience, The Netherlands. This summary gives a brief account of the results of the investigations carried out between August 1987 and September 1990, with emphasis on the water resources potential for development. This study forms the basis for the District Water Development Study for Meru District which is published as an accompanying report by the Ministry of Water Development, Nairobi, 1991.

Project Area

The area of investigations is bounded by the parallels 0° 30'S and 0° 45'N and the longitudes 37°E and 38° 30'E. It covers an area of about 9,920 km². The 1988 projected population is 1,214,950.

Meru District is wholly underlain by the Basement System rocks outcropping on the eastern part of the District. In the rest of the District they are overlain by the Tertiary sediments and volcanics and also by Quaternary volcanics and sediments.

The District is mainly drained by the Tana river and its tributaries. The northern and western parts of the District are drained by the Ewaso Ngiro river system.

Soils on the volcanic rocks are medium to highly fertile and their infiltration capacity is moderate to low. But on the upper parts of Mount Kenya soils are shallow to very shallow with rock outcrops and ice in the highest parts. While on the semi-arid Volcanic Lowlands in the northern part of the District soils are more calcareous, stony and bouldery. In the Basement System areas, soils are generally loamy sand.

The humid zones: the southern and eastern slopes of Nyambeni Hills and the eastern slopes of Mount Kenya receive annual rainfall ranging between 1,400 and 2,500 mm, while annual evaporation is less than 1,600 mm. Rainfall in the semi-arid zone is generally less than 800 mm, while evaporation is over 1,500 mm. There are two distinct rainy seasons; the long rains in March-May and the short rains in October-December.

Investigations

The basic data were gathered through study and analysis of the reports on previous studies and of the archives of the MoWD, and through field investigations. Hydrological fieldwork included rehabilitation of raingauges, installation of additional evaporation pans, stream gauging, a water permit survey and water sampling for chemical analysis. The groundwater fieldwork included geological analysis (remote sensing, ground-survey), geophysical surveys, water level monitoring and water sampling.

Water Supplies

A water survey was held in 1988/89 during which all major water supply systems were visited, while a water permit inventory was carried out in the same period to obtain information on the legal water abstractions.

There are 11 public (MoWD) water supplies in Meru District, and more than 1000 small and large self-help/community owned water projects. About 80% of the population depends on systems drawing water from rivers and springs. Other types of water supplies are based on boreholes, wells, furrows and water tanks, or on a combination of these. Valid surface water permits are issued for around 1700 different abstraction points along rivers endorsing a total dry season abstraction of 8.4.

A total of 163 boreholes were visited during the borehole inventory. Only 64 were operational. They supply water for both domestic and livestock use. These boreholes are concentrated in Igembe and Tharaka, and to a lesser extent in the newly created Ntonyiri Division. In the Igembe Division and along the windward slopes of Mt Kenya water is obtained from the numerous springs.

Water Demand

Water demand projections for domestic use and cattle watering were made for the year 1991 and 2013 using the 1979-census population and the 1983 figures for livestock estimates. The total annual domestic water demand is an estimated 41 Mm3 (equals 1.3 cumec) for 1991 and 75 (equals 2.4 cumec) for the year 2013. Rapid growth of the human population is the main cause of the increase.

Water demand for irrigation during the dry season is virtually unlimited and cannot be satisfied from dry season flow. There is about 19 cumec available for irrigation (80% probability level), which is sufficient to irrigate around 164 km2 for a water demand of 10 mm/day. Demand for large scale irrigation can only be satisfied by dams storing water from the rainy seasons.

Surface Water Resources

The higher parts (above 1500 m) of Mt Kenya and the Nyambeni Range are the most productive areas for streamflow generation (streamflow into the Tana and Ewaso Ngiro rivers is 70 and 10 cumec, respectively) mainly because of the high rainfall. In addition, rainfall is rather evenly distributed over the rainy seasons. Infiltration conditions are favourable and aquifer transmissibilities high. Groundwater emerges in numerous springs and seepages (the spring inventory identified around 560 springs, but there are many more in the unsurveyed areas), often in river beds thus becoming baseflow. As a result, most of these streams sustain high, steady baseflows.

There are however two areas situated above 1500 m without surface water: i.e. the Kirua-Kibericha and the Lare area. These are areas covered by many recent parasitic cones. Infiltration capacities are very high and aquifers very deep. There are no springs in these areas to feed the rivers during droughts. Rivers therefore are ephemeral. Elsewhere streamflow production is largely confined to the rainy seasons.

The chemical quality of surface water is good for domestic use, cattle watering and irrigation.

Groundwater Resources

The subsoil of Meru consists of two major units: the Basement System and the Tertiary Volcanics. Groundwater is found in both units and in the shallow alluvial sediments on top of these units.

The Basement System is characterized by the presence of local aquifers: this means that there are many small, isolated groundwater pockets in this unit that usually coincide with fractured and/or weathered zones. Borehole siting is therefore critical in the Basement Rocks. The most productive boreholes are those drilled in the alluvial deposits along the main rivers where water quality is usually acceptable. This is contrast to the water quality of boreholes in the Basement rocks where only about 30% is suitable for domestic use

In contrary, the Tertiary Volcanics form a predominantly regional aquifer. The parts above the 1500 m contour are characterized by systems of cascading perched aquifers: infiltrating groundwater flows downward to the main aquifer. On its way, it encounters impervious layers (e.g. lava flows or dikes). Groundwater tends to accumulate on top of such layers giving way to the formation of perched aquifers. Springs can be expected where these aquifers come close to the ground surface. Borehole yields of such small, local systems tend to be low, borehole siting is critical and should be done by an experienced hydrogeologist as there are no geophysical methods to find such perched aquifers.

Perched aquifers are missing in the two zones with recent parasitic volcanic activity: the Lare and Kibericha-Kirua areas. Here, infiltrating groundwater percolates downward unhindered by impervious layers. It is likely that these zones are underlain by very productive aquifers at greater depth.

Below the 1500 m contour, there is a continuous deep aquifer in most of this unit: the water of this aquifer discharged by the springs near the Ewaso Ngiro is recharged in the higher parts of Mt Kenya or the Nyambenis.

The chemical quality of groundwater from the volcanics is generally good enough for domestic use. Locally, fluoride exceeds the permitted levels.

Surface Water Development Potential

There is ample potential left in Meru District for development of surface water for domestic use and even for development of low flows for irrigation. Construction of additional streamflow intakes for irrigation can be considered.

The available low flow with a probability level of 80% (design flow for irrigation projects) of 20 cumec (equals around 630 Mm3/year) is sufficient to irrigate an area of about 200 km2 given an irrigation requirement of about 10 mm/day. This acreage could be substantially increased with proper storage facilities (dams) along the main rivers.

In some of the semi-arid areas of Tharaka where the distance to the nearest perennial stream is too large, sub-surface dams and sand-filled dams in the beds of seasonal rivers may provide reliable water points, particularly for cattle watering. Roof catchments can be an important supplementary source of drinking water provided that the storage tank is properly constructed.

However, the chemical and biological quality of the water is in danger as more than 100 coffee factories dispose their effluent without proper treatment into the rivers. Unfortunately, peak coffee production coincides with the onset of low flows when dilution is not as strong as during the rainy season. So, the poisonous coffee effluent is discharged into the streams in a time when about 70% of the population depends on river flow for their drinking water. Only strict law enforcement on curbing illegal waste water disposal could alleviate this situation.

Groundwater Development Potential

Large parts of Meru District have more than sufficient surface water to satisfy present and future demands. Baseflow in many of these areas originates from spring water which ensures a permanent supply throughout the dry season. Groundwater supply from boreholes is then an expensive alternative which may not be economically feasible for many types of use. However, where the quality of surface water is unsuitable for domestic use during a large part of the year, groundwater supply from springs, boreholes or dug wells should be considered. The benefits in the form of reduced incidence of illnesses may outweigh the high costs of construction or treatment.

In the eastern slopes of Mount Kenya and the western part of the Nyambeni Uplands springs are almost everywhere and as such their development is preferred.

In the leeward slopes of Mount Kenya and the Volcanic Plains including the Northern Grazing Area where springs are few or non-existent, water supply from boreholes is considered generally feasible for domestic use.

Only the Kibericha-Kirua and the Lare Areas lack surface water. Groundwater is extremely deep and development is considered highly questionable.

In the Tharaka Basement Area the only option for groundwater supply is drilling of boreholes. There are many local aquifers with limited supply capacity and water of acceptable quality, but their siting requires hydrogeological and geophysical surveys.

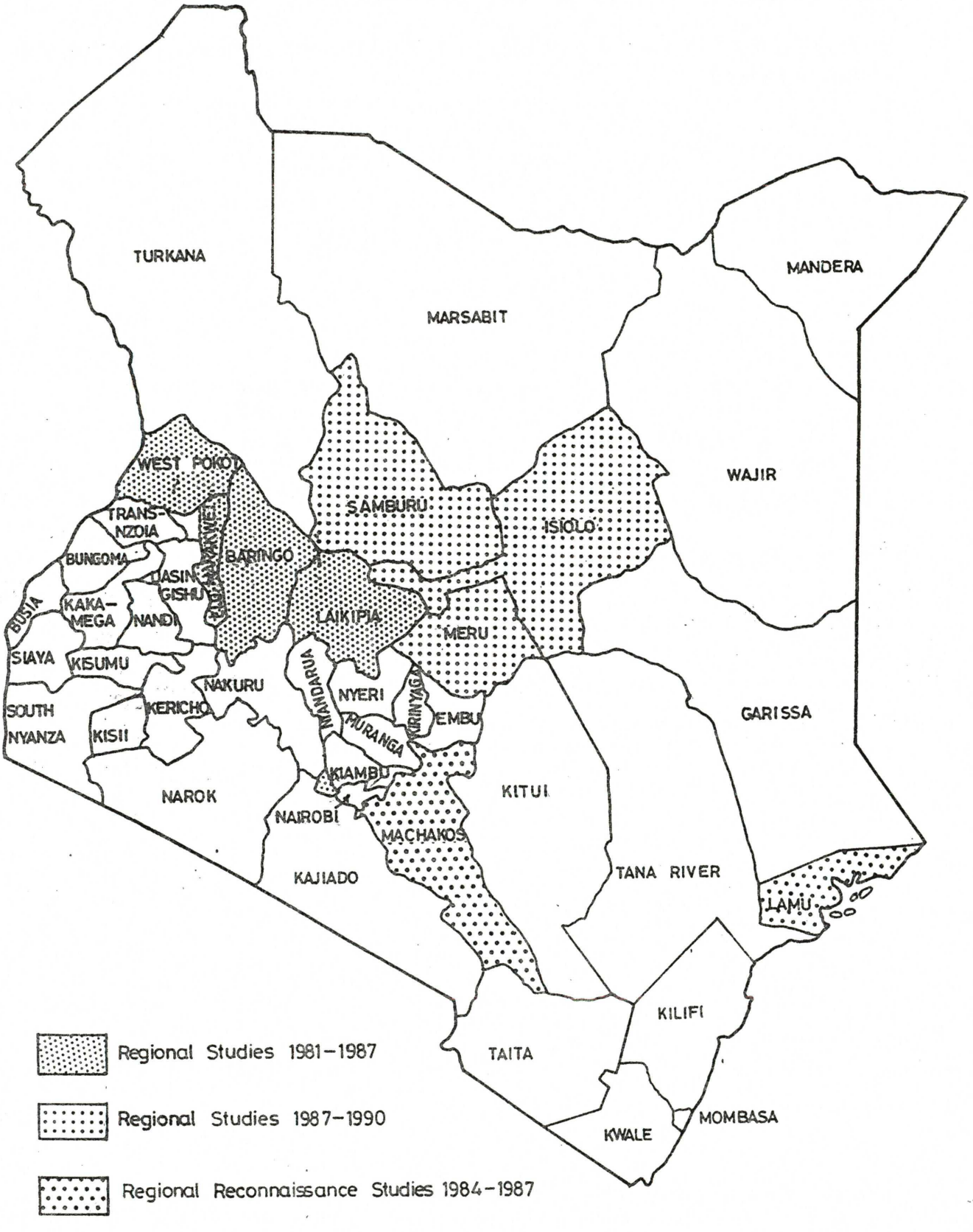
CONCLUSIONS

There are probably few Districts in Kenya endowed with so much water, both groundwater and surface water. Meru District has sufficient water potential to meet easily current and future (year 2013) domestic water demand. Water demand can be easily met by springs or streamflow, even during severe dry seasons. Water demand in the Northern Grazing Area, without permanent rivers, can be easily met by groundwater as the underground is very productive. Only the Kibericha-Kirua, and the Lare area lack surface water while groundwater is very deep. There is reason to believe that there are productive aquifers at great depth. Nevertheless, these areas are quite small and water can be piped from adjacent areas to solve the supply problem.

In general, spring water supply is preferable because of its high reliability and low operating costs. Surface water is a good alternative but it is often polluted by coffee waste. Groundwater is almost everywhere available at economic depth.

In Meru District soils are not considered a limiting factor in development of the areas if water is available.

WATER RESOURCES ASSESSMENT & PLANNING PROJECT



1.1 Regional Assessment Studies under the WRAP Programme 1981-1990

1. INTRODUCTION TO THE PROJECT AREA

1.1 Location of the District

The area of investigations is bounded by the parallels 0° 30'S and 0° 45'N and the longitudes 37°E and 38° 30'E (Figure 1).

Meru District is located in the Eastern Province and is bounded by six districts: Isiolo to the north and east; Kitui and Embu to the south, Kirinyaga and Nyeri to the south-west and Laikipia to the north-west. It covers an area of about 9,920 sq km. The District is administratively divided into nine Divisions, 48 Locations and 145 Sub-locations.

1.2 Physiography

Four main physiographic units can be distinguished in the District. They are:
(i) Mount Kenya, (ii) The Nyambeni Range, (iii) The Volcanic Plains and
(iv) The Basement System Area

Mount Kenya

Mount Kenya can be further sudivided into the Upper, the Middle and the Lower Volcanic Slopes.

The *Upper Volcanic Slopes* of Mount Kenya (5199 m) are situated above approximately 3500 m. This zone coincides rather well with the former glaciation. At present it comprises a glacial-naval subzone, an afro-alpine subzone and a moorland subzone. Several glaciers drain to the Ewaso Ngiro and Tana catchment, but contrary to popular belief, total discharge from this area is small. The area is mainly a recharge area with a deep groundwater table, though locally shallow groundwater and moorlands occur which are associated with perched aquifers.

The *Middle Volcanic Slopes* extend from around 2500 m to 3500 m. They are covered with forests which tend to thin out to the north-eastern leeward side of the mountain where little true forest is left. These areas enjoy the highest rainfall and supply a substantial part of the perennial runoff. The terrain is often rugged and the rivers deeply incised. It is a groundwater recharge and transmission area but at lower elevations many springs occur.

The *Lower Volcanic Slopes* of Mount Kenya are used for rainfed agriculture. They are among the best lands in the country. The terrain is hilly to rolling though steep sloping rugged parts also exists. Stream incision generally decreases in a downstream direction as does rainfall. The landscape has a humid appearance in the upper part of the zone and a semi arid character in the lower parts. The groundwater table is predominantly shallow at the transition zone between the Upper and Middle Volcanic Slopes but falls gradually to greater depth in downstream directions. Few springs occur on the leeward side of the mountain, but many in the transition zone on the eastern side of the mountain where rainfall is higher. This area is mainly a groundwater transfer zone although some recharge might occur in the upper humid parts.

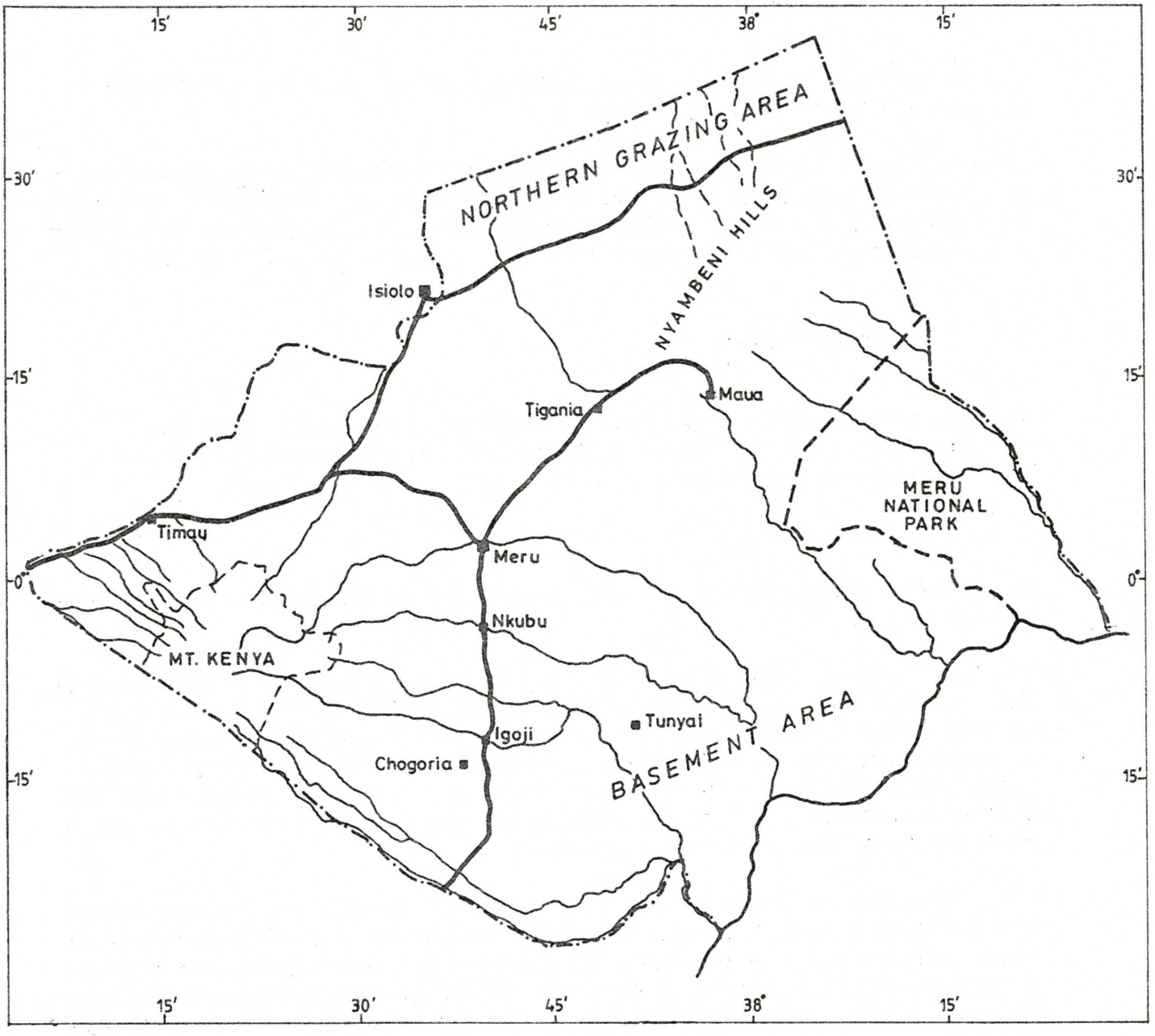


Figure 1.2 Map of Meru District

Nyambeni Volcanic Range

The Nyambeni Volcanic Range (2514 m) is elongated in a north-east to south-west direction from the foothills of Mount Kenya and shows superficially a lot of similarity with the Lower Volcanic Slopes of Mount Kenya. The soils are among the best in the country and used for rainfed agriculture. The terrain in generally steep although flat or hilly parts also occur, notably near the summit. The landscape has a humid appearance in the upper and middle parts and a semi-arid in the lower parts. The groundwater table is predominantly shallow but can be deep at the top of the range. Many springs are found on the windward side of the range and fewer on the leeward side. Springs are fewer but carry much more discharge than those at Mount Kenya. Recharge takes place in the rainy upper parts of the range while most discharge occurs through many large springs on the contact between the Volcanics and the underlying Basement.

Volcanic Plains

The Volcanic Lowlands lie roughly between 1500 and 2000 metres contourlines. The climate is semi-arid. They are formed by lavas which have been extruded from the Nyambeni Range, and to a lesser extent from Mount Kenya. The topography is mostly flat to gently ondulating with rivers flowing through narrow valleys.

Basement System Area

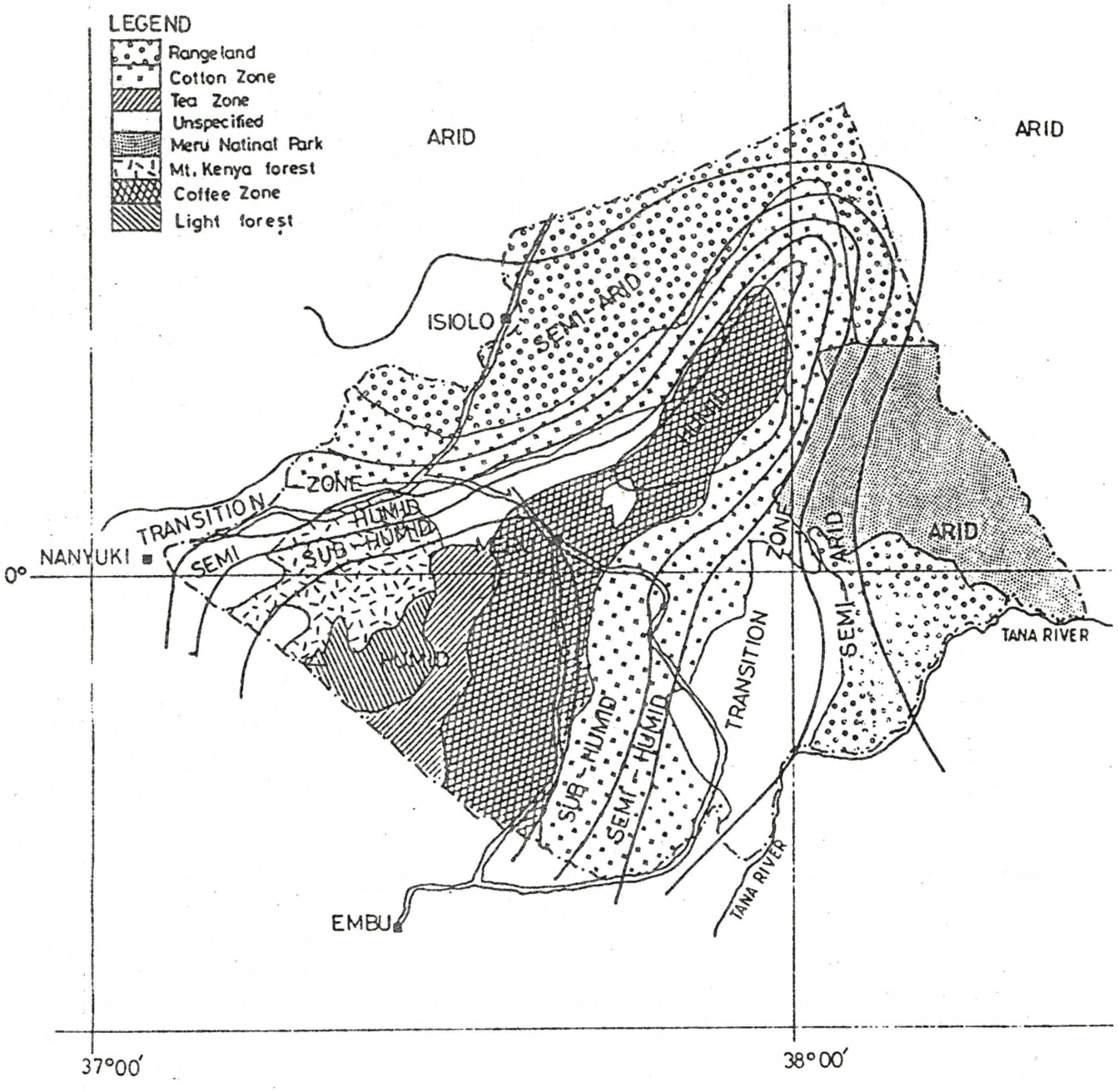
The Basement System Area is considered a separate unit. The appearance of the rocks and the terrain is very different from that of the volcanic areas as are the groundwater, surface water and climatic conditions. The Basement Area can be characterised as a dusty arid plain dotted with Inselbergs and bare rugged mountains.

The present land surface in the Basement area has been eroded well below the sub-Miocene peneplain which is a sub-volcanic floor, only preserved intact below protective lava layers or as degraded remnants of resistant metamorphic rocks. This surface occurs between 1200 and 1350 metres at the eastern and south-eastern margins of Mount Kenya. The second peneplain, the end-Tertiairy or mid-Pliocene peneplain is more important. It occurs at elevations between 1000 and 1200 metres. According to Baker (1967) vulcanism of Mount Kenya began just before the maturation of this peneplain while it is the floor on which the Nyambeni Volcanic Ranges were built up.

1.3 Climate

The climate is strongly associated with altitude. It is arid at altitudes of less than 15,500 m and semi-arid from 1,500 to 2,000 (Figure 1.3 and Plate 4.1). Rainfall in the semi-arid zone is generally less than 700 mm while the evaporation exceeds 1,800 mm. The humid and semi-humid highlands experience rainfalls of over 1,000 mm and evaporation of less than 1,500 mm. A transition zone lies in between the semi-humid and semi-arid areas.

There are two distinct rainy seasons: the Long Rains in April-May and the Short Rains in November-December. In between there is a relatively dry period during which it rains occasionally. The period January-March is very dry.



Name	Mean Annual Rainfall (mm)	Rainfall/Potential Evaporanspiration (%)	Main Cash Crops	Main Food Crops	Yields
Humid	1100 - 2700	>80	Tea, Coffee	Wheat, Maize	High
Sub-Humid	1000 - 1600	65 - 80	Coffee, Cotton	Beans	High
Semi-Humid	800 - 1400	50 - 65	Cotton	Potatoes	Moderate
Transition-Zone	600 - 1100	40 - 50	Cotton	Bananas	Low
Semi-Arid	450 - 900	25 - 40	-	Almost no	
Arid	300 - 550	15 - 25	-	Crops	

Figure 1.3 Landuse, Main Crops and Agroclimatic Zones

1.4 Drainage System

The drainage system is mainly determined by three factors: (i) the direction of the slope of Mount Kenya and the Nyambeni Range, (ii) the slope of the end Tertiary peneplain and (iii) the Basement System structures.

Radial and near-radial drainage patterns predominate on the slopes of Mount Kenya and the Nyambeni Range, untill the mountain streams debouch from the gorges in the lavas onto the Basement System floor. The rivers on the western and northern slopes, viz the Timau, the Sirimon and Isiolo Rivers are tributaries of the Ewaso Ngiro as are the ephemeral streams on the northern slopes of the Nyambeni Range. All other rivers, viz. the Thuchi, Mutonga, Thangatha, Kathita and Ura River are tributaries of the Tana River.

Most of the tributaries originating from the upper and Middle Volcanic Slopes are perennial while the majority of the streams are rising on the Lower Slopes, the Volcanic Lowlands and the Basement System are ephemeral. Also the streams on the north-western flanks of the Nyambeni Range are intermittent.

The drainage in the Basement System areas usually is generally controlled by the strike and dip joints of the rocks.

1.5 Soils and Landuse

The soil distribution in the study area is mainly determined by the parent rock and the climate.

Soils on the volcanic rocks are shallow to moderately deep, dark reddish to dark brown, well drained soils with clayey loam to clayey sub-soils. They are medium to highly fertile and their infiltration capacity is moderate to low. Soils on the upper parts of Mount Kenya are shallow to very shallow with rock outcrops and ice in the highest parts. Soils on the semi-arid Volcanic Lowlands in the northern part of the district are of the same type, but more calcareous and more stony and bouldery.

In the Basement System areas in the south-east of the study area rocks mainly consists of banded gneisses. Soils in this area are generally well drained and moderately deep. They consist dark red to yellowish red sandy clay to clay with a top-soil of loamy sand.

According to the District Data sheet prepared by the Ministry of Agriculture, Meru District has 651,000 ha. of agricultural land, broken down as shown in Table 1.

On high potential areas mainly tea, coffee, potatoes and maize are grown while cotton, tabacco, sunflower, sorghum and millet are produced in medium and marginal zones.

The potential irrigation area in the District is an estimated 10 000 ha. Currently only about 1000 ha is under irrigation, mainly by group-based small holder schemes. Most of the schemes are furrow systems.

Table 1.1 Land Classification of Meru District

Category	Area (ha)
High Potential	241 000
Medium Potential	95 000
Low Potential	315 000
Forests	139 700
National Parks	125 000
Other	76 500

Source: Meru District Development Plan 1989/93

Figure 3 depicts the relationship between moisture availability zones and agro-zones as shown in the Meru District Development Plan 1989/93.

1.6 Population

In 1969, Meru District had a population of 596 506 and in 1979 a population of 830 179. The intercensal population growth rate from 1969 to 1979 was 3.4%. The Central Bureau of Statistics values the annual population growth rate from 1980 to 1988 at 3.91%. Using this estimate, the projected population on divisional level in Meru District is as in Table 2.

Table 1.2 Population Projections 1979 - 1988

Division	1979	1983	1988
North Imenti	198 434	238 764	290 404
Timau	23 389	28 143	34 229
South Imenti	103 543	124 587	151 533
Nithi	142 288	171 207	208 236
Tigania	140 651	169 237	205 840
Tharaka	50 277	60 495	73 579
Igembe	171 597	206 472	251 129
Total	830 179	998 905	1 214 950

Sources: Central Bureau of Statistics, Kenya
Population Census 1979, Volume 1
June 1981 Central Bureau of Statistics,
Population Projections 1980-2000, March 1983

The average population density for 1979 was 84 persons per km² given an area of 9922 km². However, excluding non-residential areas like forests and parks, the remaining residential area is only 7460 km². This implies a population density of 111 in 1979, 134 in 1983 and 163 in 1988.

It appears that the North Imenti has the largest population and Timau the lowest. Timau has the lowest population density of the district because it was a sceduled area and settlement is still taking place. South Imenti has the highest density because most of the area is fertile and well settled.

Table 1.3 Estimated population Densities in 1988 in Meru

Division	Residential Area km2	Population Density
North Imenti	918	316
Timau	790	43
South Imenti	392	387
Nithi	640	325
Tigania	652	316
Tharaka	1,496	49
Igembe	2,572	98
Total	7,460	163

Source: Meru District Development Plan 1984/88

1.7 Livestock

Although there has not been a recent livestock census, estimates of livestock numbers by the Ministry of Livestock Development are available based on their dipping and vaccination statistics. The latest data on livestock production date back from 1986/87.

WRAP carried out a livestock census in collaboration with the local administration and divisional livestock offices to obtain livestock numbers for all sub-locations in the District.

The data are summarized in Table 4.

Table 1.4 Livestock in Meru District

Type	1977	1982	1984	1986	1988
Grade cattle	44 098	94 917	46 589	66 982	214 709
Beef Cattle	832 627	261 018	200 984	224 590	151 987
Sheep	469 260	312 525			
Goats	647 461	322 854	525 000	555 552	482 613
Pigs	2 341	5 066			
Poultry	318 445	932 883	73 000	842 041	
Donkeys	2 949	19 653		4 621	
Bee Hives	27 150	76 527			

Source: Meru District Development Plan 1984/88

Grade cows do well in high to medium potential areas while marginal areas and range areas tend to support only native cattle.

1.8 Water Supply and Water Demand Projection

A water survey held in 1988/89 showed that there are 11 public (MoWD) water supplies in Meru District, and more than 1000 small and large self-help/community owned water projects.

Around 80% of the population depends on systems drawing water from rivers and springs. Valid surface water permits have been issued for around 1700 abstraction points along rivers, endorsing a total dry season abstraction of 8.4 cumec.

Other water supplies are based on groundwater abstraction, rainwater collection or a combination of these. Out of 163 boreholes visited during the borehole inventory, only 64 were operational (Figure 4). They supply water for both domestic and livestock use. These boreholes are concentrated in Igembe and Tharaka, and to a lesser extent in the newly created Ntonyiri Division. In the Igembe Division and along the windward slopes of Mt Kenya water is obtained from springs.

A household survey carried out in the area between Nkubu and Usueni shows the following use pattern.

Table 1.5 Water sources

	% of population Using Water From:	
	Rainy Season	Dry Season
Rivers	57%	70%
Springs	12%	10%
Wells	6%	5%
Boreholes	5%	no data
Furrows	14%	9%
Water tanks	4%	no data

Water demand projections for domestic use and cattle watering were made for the years 1991 and 2013 using the 1979-census population and the 1983 figures for livestock (see District Water Development Study - Part 1). The annual domestic water demand is estimated at 41 million m^3 (equal to 1.3 cumec) for 1991 and 75 million m^3 (equal to 2.4 cumec) for 2013. Rapid growth of the human population is the main cause of the increase. Water demand for irrigation during the dry season is virtually unlimited and cannot be satisfied from dry season flow.

2. GEOLOGY

2.1 Previous Geological Studies

The first studies on the geology of Meru District were conducted by Chanler (1893), Gregory (1900), Broun (1906) and Archer (1913). Several exploratory visits followed during the next decades, but systematic mapping by the Geological Survey of Kenya started only in the fourties. Shackleton (1946) began with the western part of the area. The area between Embu and Meru followed within five years (Schoeman, 1951). A few years later the south-western and central parts of the District were mapped by respectively Dodson (1955) and Mason (1955). The remainder of the District was finalized in the sixties by Williams (1966), Baker (1967), Jennings (1967) and Rix (1967). The boundaries of the respective study areas are indicated in figure 2.1.

The geological map of the District (Plate 2.1) is based on these studies. Meru District is wholly covered by aerial photographs and satellite images.

The above reports provide the basic information on geomorphology, lithostratigraphy and structural features of the Meru region and give also a brief summary on the availability of surface and groundwater.

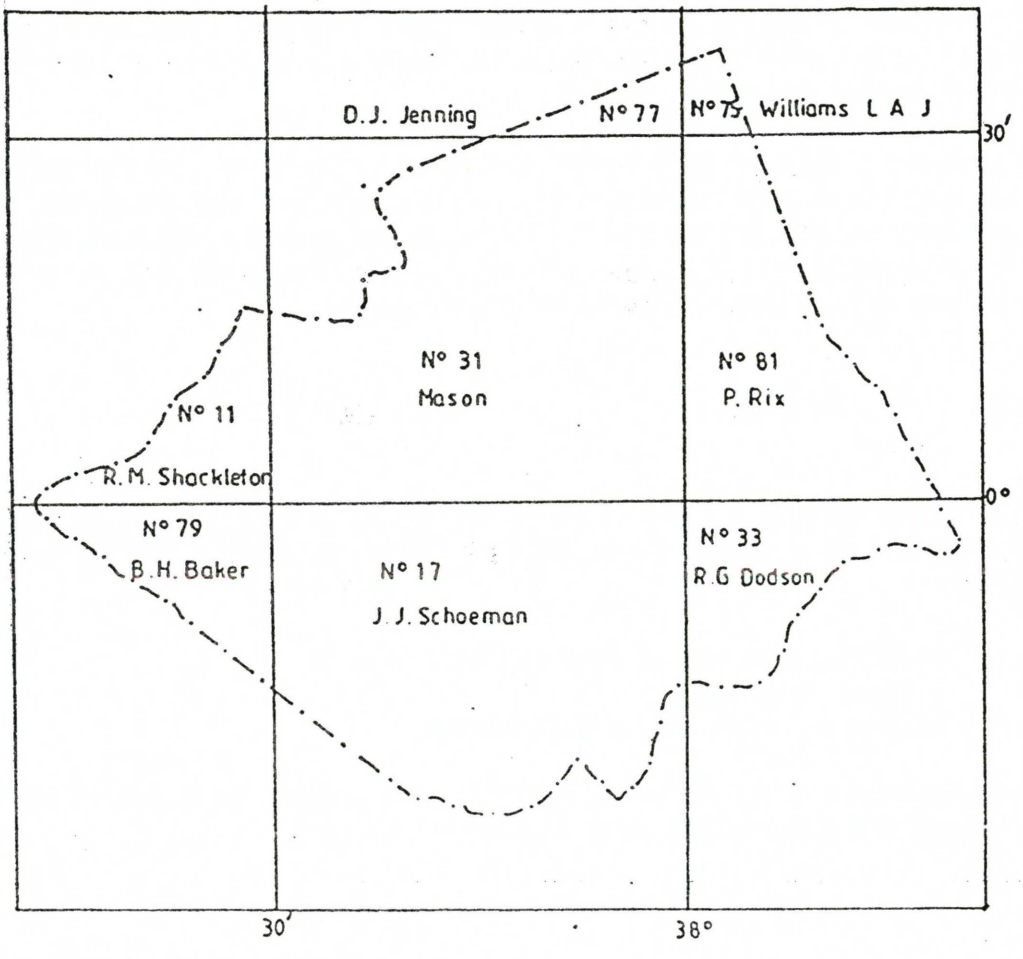


Figure 2.1 Available Geological Reports

2.2 Geological Setting and History

Meru District lies to the eastern side of the East African Rift Valley and is wholly underlain by the Precambrian Basement System. The huge volcanic complexes of Mount Kenya and the Nyambeni Range occupy most of the western and north-western parts of the District. From these major eruption centres, and a large number of smaller ones, lava flows diverged to the surrounding low lying areas.

The rocks in the higher parts of the study area are mainly volcanic: phonolytes, Kenyte lavas, basalts, trachytes and tuffs. But the metamorphic rocks of the Basement System predominate in the lower areas.

The geological history of the area can be followed from the Precambrian era represented by the Basement System. Successive stages of uplift and erosion lasting until the beginning of the Tertiary have resulted in removal of the upper layers of the Basement System and any other overlying younger layers which might have been deposited. As a result the Sub-Miocene or Early Tertiary peneplain originated. This is an erosion surface underlying the Tertiary and Quaternary volcanics. Remnants of it can be found throughout Central Africa.

Subsequently a great series of lava sheets flooded out from the area which is at present the Rift Valley. The main boundary faults of the Rift Valley originated after deposition of these lava flows, according to Mc Call (1967).

After this, a prolonged period of relative stability began. The resulting land surface is known as the End-Tertiary peneplain. Generally, it lies a few hundred metres below the Sub-Miocene peneplain.

According to Baker (1967) the volcanicity of Mount Kenya began shortly before the maturation of this peneplain and this was followed by the eruption and build-up of the Nyambeni Range. Subsequently, a large part of the District was covered by lava flows. The youngest rocks in the area are the products of the parasitic cones which originated from both Mount Kenya and the Nyambeni Range.

2.3 Stratigraphy

The stratigraphy of the District is mainly based on the geological reports listed in Section 2.1. According to these, the rock formations in Meru can be divided into three groups.

1. Metamorphic rocks of the Basement System
2. Tertiary Volcanics
3. Quartenary Volcanics and Sediments

The distribution of the rock formations in the project area is shown on Plate 2.1. A summary of the lithostratigraphy is given in Table 2.1.

2.3.1 Basement System

The Precambrian Basement rocks are the oldest in the area forming the floor upon which the other rock units rest. They are believed to belong to the Mozambique orogenic belt of East Africa. They comprise various types of sediments which were transformed by regional metamorphism into gneisses, schists and quarzites.

Table 2.1 Simplified Lithostratigraphic Table of Meru District

Mount Kenya Area

PERIOD	EPOCH	FORMATION		LITHOLOGY	maximum THICK-NESS (metres)
QUATERNARY	RECENT	Superficial Deposits		Loam,silt,clay,laterites,gravel ashes,young and old moraines	
QUATERNARY	PLEISTOCENE	MOUNT KENYA VOLCANIC SERIES	Upper (parasitic vents)	Basaltic pumice, scoracious lavas	200-300
			Middle (parasitic fissure eruptions)	Trachytes,olivine basalts, mugurites,olivine trachytes	>500
			Lower (main eruptive episode)	Nepheline syenite of the plug Kenytes,phonolites Phonolites and trachytes Unexposed volcanics	- 600 >500 3000
TERTIARY	PLIOCENE		end-Tertiary peneplain		
PRE-CAMBRIAN		Basement System		Pelitic to semi-pelitic gneisses,granitoid gneisses, pegmatites,schists, Mt Kenya charnockitic rock (dioritic) interbedded with semi-pelitic gneisses	
		Intrusives		Gabbros,olivine dolerites, perknites	

Nyambeni Area

PERIOD	EPOCH	FORMATION		LITHOLOGY	maximum THICK-NESS (metres)
QUATERNARY	RECENT	Superficial Deposits		Loam,silt,clay,laterites,gravel ashes,calcretes	
QUATERNARY	PLEISTOCENE	NYAMBENI VOLCANIC SERIES	Parasitic vents	Basaltic pumice, scoracious lavas	60-100
			Upper	Basalts,phonolites,tephrites scoracious lavas,tuffs	1070
			Lower	Porphiric olivine basalts	30-300
			Lakebeds	Friable limestone	
			end-Tertiary peneplain		
PRE-CAMBRIAN		Basement System		Pelitic to semi-pelitic gneisses,granitoid gneisses, pegmatites,schists	
		Intrusives		Perkinites	

Basement System rocks outcrop on the eastern and southern parts of the District.

A number of isolated inlayers within the Tertiary volcanics can be traced consisting of metasediments of various composition, e.g. psammitic, pelitic and calcareous types, migmatites and intrusives.

The psammitic type are resistant to weathering, hence form ridges and hills. Most of the Basement system rocks consist of semi-pelitic metasediments.

2.3.2 Tertiary Sediments

These rocks do not outcrop in the project area.

2.3.3 Tertiary Volcanics

The volcanic rocks in Meru are products of eruptions which took place from the Miocene until the Middle-Pliocene.

These are of two series.

(a) The Mount Kenya Volcanic Series
(b) The Nyambeni Volcanic Series

The Mount Kenya Volcanic Series

These rocks outcrop in the western part of the area around Mount Kenya covering an area of around 7,000 km^2. The series consist of the lowermost flows being the olivine basalt which underlie the Kenytes which are themselves underlain by tuffs and agglomerates, especially to the area north of Kitui. In the north, the Kenytes have a negligible thickness but to the south the flow is up to 100 m thick. The Kenytes are followed by finely porphyritic or dense phonolites and tuffs with thickness up to 600 m. To the north-east, phonolites overlie the olivine basalts. Within the study area there are several well preserved craters representing the latest manifestations of volcanism. Their recent eruption of basalts, tuffs and ashes happen to be the youngest outcrops, but are of limited extent.

The Nyambeni Volcanic Series

This series mainly outcrops in the central and in most of the northern part of the district and consists of:

(a) The Lower Nyambeni Basaltic lavas
(b) The Upper Nyambeni Basaltic lavas and
(c) Basalt with intercalations of phonolites, ashes and tuffs of the parasitic vents.

The Lower Nyambeni Basalts are porphyritic and vesicular. They are of olivine bearing type. A clear distinction between the Lower Mount Kenya and Lower Nyambene can be seen at two areas, Meru-Kanjai road and in the Kasita river section. Thickness varies from 30 to 300 m, the thickest part being in the middle of the range.

The Upper Nyambeni Series consist of the phonolites, tephrites, olivine basalts, trachy-andesites interceded with tuffs, ashes and scoraceous lavas of volcanic vents. The phonolites, porphyritic phonolites and tephrites building the main Nyambeni Range extend in a south-west to north-east direction across the area, with a thickness of up to 1,070 m. Volcanicity in the Nyambeni region continued longest towards the northeast as is evidenced by the rapid increase in the number of vents and recognizable craters in that direction. Their products were ash or ash and lava.

2.3.3 Quaternary Volcanics

The Quaternary volcanic rocks in Meru are parasitic events' products of eruptions which occurred during the late Pleistocene Age. They are located around the volcanic cones and consist mainly of lavas (scoracious), phonolites and ashes.

2.3.4 Quaternary Sediments

The Quaternary sediments in the area are made up of superficial deposits of both Pleistocene and Recent which are in localised patches of various types. They are lake beds mainly made of fossiliferous limestones located Ndianday on the Rojewero River. The gravels are chiefly derived from Mount Kenya or Nyambeni Basalts depending on where they are found. Conglomerates occurring in patches within the area, can be spotted at Lansa Hills and on river Kireira. Fluvial sediments have been exposed by the rejuvenated streams which are few and localized.

2.4 Structures

No major faults are indicated on the geological maps. However, there is a concentration of minor faults to the south eastern part of the district around Chiokariga, Mutejewa, Maatha and Kalangachini. Faults are easily detected in the Basement Area and trend in a north - south direction.

In the volcanic areas, major structures are the craters and vents. There is a suggestion of a fracture or fissures running across the southern slopes of Mount Kenya, indicated by the occurrence of ten basaltic craters, lying nearly on a straight line (Tigwa, Keheri, Gerere and the craters of the upper Nyamidi, Rupingazi, Ruguti and Nithi valleys). These are similar in age to those on the north-eastern part of the Nyambeni Range. The Nyambeni types are aligned along fissures with a northerly trend.

3. GEOPHYSICS

3.1 Introduction

This chapter summarizes the geophysical investigations carried out by the Water Resources Assessment and Planning Project in Meru District.

Volcanic deposits occupy about 80% of Meru District. These deposits are underlain by impervious methamorphic rocks that surface in the rest of the District. Since the volcanic rocks in certain conditions may form good aquifers, it is important for the ground water assessment study to determine their vertical and lateral extent.

Therefore, a survey of Vertical Electrical Soundings (VES) was carried out to establish the total thickness of the various volcanic deposits, that cover the basement. It was also tried to correlate the electrical resistivities of layer units with the aquifer properties of these deposits in different areas by means of exploratory drilling and pumping tests.

Geophysical work started in late 1987 in the volcanic planes surrounding the Nyambeni Range as a feasibility study to assess the applicability of the VES-method.

On the base of the positive results, a more extensive survey was undertaken in the Nyambeni volcanic plains and also in the eastern terminal slopes of the Mount Kenya Volcanic System. The topographically high volcanic areas and the basement areas in the east and southeast of Meru District were not included in this study for reasons given in section 3.3.

The details of the geophysical study, the final interpretation of the data collected and the results of the drilling programme are given in appendix 3.1 through 3.3.

3.2 Previous Geophysical Studies

In recent years a large number of Vertical Electrical Soundings was executed for borehole siting in Meru District by the District Office of the Ministry of Water Development in Embu. Most of these were carried out for Plan International in Igembe division which is in the area under investigation by WRAP. Others for the Swedish International Development Agency (SIDA) are in the Tharaka Division basement area, and elsewhere in Meru District.

Although the Igembe soundings are generally of good quality, their electrode distances are far to short for the determination of the total thickness of the volcanic deposits, which is the main aim of the geophysical studies. Also, there is no reliable map showing the exactly location of the soundings.

Groundwater Survey (Kenya) Limited carried out several local studies in the northwestern lower Nyambeni volcanic planes and also in the Igoji - Chuka area of the eastern Mount Kenya Volcanic suite.

A geohydrological survey was carried out in southwestern Meru and the adjacent areas of Embu as part of a MSc thesis by T. Veldkamp and Ph. Visser in 1985-86. This study consisted of a limited number of short range vertical electrical soundings and electrical profiles.

3.3 Geophysical Fieldwork

As mentioned in section 3.1, geophysical field work was started with a limited number of VES as a feasibility study, followed by a more extensive study in selected areas.

On geo-morphological basis, considering also the main objective of the present geophysical study, Meru District can be subdivided into 3 major units.

(i) The volcanic mountain ranges and foothills of Mount Kenya and Nyambeni, roughly above the 1500 m level.

(ii) The volcanic plains surrounding these ranges below the 1500 m level

(iii) The Basement system areas bordering the volcanic deposits (Meru National Park, Tharaka Division).

Units (i) and (iii) were discarded for further geophysical investigations because of the following reasons.

- From the VES feasibility survey it was concluded that the volcanic - basement interface lies beyond the reach of the soundings in the topographically high areas. A reasonable success in determining the volcanic thickness is only possible roughly below the 1500 m level. Moreover, in the volcanic ranges and in the high plateaus the static water level of the main aquifer is too deep for economic exploitation. Though scattered water pockets (perched aquifers) occur in the non-saturated zone, their localization by means of VES is highly questionable because of the extremely complex nature of the rock-type distribution in these eruptive volcanic environments.

- In the Basement area of Tharaka Division, investigated by SIDA, sufficient data are already available for groundwater assessment. In Meru National Park and adjacent Basement areas similar geohydrological conditions can be expected.

Therefore, the geophysical studies in the District were focused on the lower Mount Kenya slopes, east of the main Embu-Meru road, and on the volcanic planes surrounding the Nyambeni Range. For the purpose of geophysical investigations the Nyambeni planes were further sub-divided into the following geographical zones:

- the Northern Grazing Area
- the Southern Nyambeni Plains interrupted by basement hills (inliers)
- the Eastern Nyambeni Plains, a continuous volcanic cover including the western part of the Meru National Park.

Thirty two VES soundings were carried out as part of the feasibility study, two of them in the Nyambeni Range. In total 186 VES were executed, more or less equally distributed over the investigated zones. Only the Northern Grazing Area was poorly covered, especially it's eastern part, by lack of access roads.

The numbering of the VES soundings follows the topographic map sheet system. The soundings have the corresponding map sheet number, followed by a serial number. The location of the soundings is given on Plate 3.1.

An electric borehole logging was done in well C7926 in the Northern Grazing Area in order to establish the true resistivity of the different volcanic deposits beneath the static water level (appendix 3.4). Unfortunately due to several adverse conditions, no other borehole log could be taken.

3.4 Data Processing, Interpretation and Correlation

The geophysical field data were stored in a computerized data base system, especially designed for the processing of data for the present assessment study.

A quantitative interpretation of the VES was done using the indirect method, based on the TNO VES, program version 4.20-S. The interpreted data, i.e. layer thicknesses and layer resistivities, were correlated to geological or hydrogeological layer units. In most cases, re-interpretation was carried out after the completion of the exploratory boreholes.

In the soundings, the deepest interface generally represents the contact between the lower boundary of the volcanic deposits and the (very high-resistivity) basement. Between this interface and the surface, a variable number of layers may be interpreted with resistivities ranging from less than 10 ohmm to more than 1000 ohmm.

Resistivity values lower than 40 ohmm can be correlated with clayey material such as volcanic ashes, water saturated pyroclastics as well as fine grained fluvial or mudstream deposits. Extreme high resistivities (>500 ohmm), represent solidified lava beds (basalt, phonolite etc) or coarse grained pyraclostics in the unsaturated zone. Intermediate values often correspond with the average resistivity of a number of individual layers that constitute the interpreted layer. Due to the decreasing resolution power of the VES method with increasing depth these individual layers cannot be distinguished at greater depths.

Former and recent drilling results show, that both high resistivity effluents and low resistivity unconsolidated deposits might produce high yielding aquifers. Therefore, it is practically impossible to detect favourable and less favourable borehole sites on the base of resistivity values only.

However, it is possible to delimitate regional lithological units on the basis of their characteristic resistivities and establish their water producing capacity by means of a comprehensive test hole program . However, the number of boreholes included within the present study was too low to give a reliable coverage over the whole investigated area.

Moreover, due to drilling difficulties, in most cases only the upper aquifer could be reached and tested.

3.5 Results

General

About 8 percent of the District area is covered by volcanic deposits. Metamorphic rocks underlying these deposits surface in the remaining 20 percent of the District area. As most volcanic rocks have proved to be good aquifers and the Basement rocks can generally be considered impervious, knowledge about the extension, thickness and water bearing properties of the volcanic formations was considered of great importance. Therefore, the geophysical investigations have been focused on improving the insight in the groundwater potential of these volcanic formations.

From the VES feasibility survey it was concluded that the volcanic - basement interface lies beyond the reach of the soundings in the topographically high areas. A reasonable success in determining the thickness of the volcanic deposits is only possible roughly below the 1,500 m level. Topographically higher situated areas had to be discarded for that reason.

Due to sufficient resistivity contrast, the vertical electrical soundings give a reliable picture of the depth to the impervious basement rocks (equal to the thickness of the mainly volcanic overburden) in the investigated area.

On the basis of interpretation of VES soundings and the analysis of borehole data a contour map of the extent and thickness of the volcanic overburden has been constructed (Plate 3.1). The map also shows the geological contact between basement outcrops and volcanic material. The contact taken from the original geological map has been corrected on the base of the VES interpretation results. These corrections have also been incorporated in the final version of the geological map (Plate 2.1).

Eastern Mount Kenya Slopes

The investigated part includes the area east of the Embu-Meru main road between Igoji and Nkubu townships and the Tharaka basement outcrops. A very deep trough running roughly in north - south direction, is interrupted in it's central part by a spur of the Tharaka basement belt. The majority of the soundings shows a characteristic resistivity value of 25 ohmm. Only a few soundings show higher resistivities.

In order to identify the kind of deposit to be correlated with the mentioned resistivity value and to test its aquiferous properties, borehole C8975 was drilled at the Magutuni dispensary . The borehole with a final depth of 180 m reached basement at 175 m. On top of the basement mainly impervious tuff (consolidated volcanic ash and pyroclastics) and mudflow deposits were found. In the upper weathered part of the tuff a low yield perched aquifer was exposed yielding about 1 m^3/h.

The whole area consisting of similar deposits is expected to produce such very low yields.

Northern Grazing Area

The area covers the low lying volcanic plateau between the Mount Kenya, the Nyambeni Ranges and the Ewaso Ngiro River; the northernmost part of it belongs to Isiolo District.

The major part of this area is semi-arid with low to moderate rainfall and infiltration. However, the many high yield springs along the Ewaso Nyiro at the contact zone between volcanic and basement rocks, indicate a copious subsurface flow. The source of this flow is undoubtedly the high precipitation and infiltration in the Mount Kenya and Nyambeni ranges.

The subsoil consists of alternating layers of basalts and a wide range of loose volcanic material from ashes to huge boulders, the lava component being more dominant close to the mountains and in the west. In the central northern part of the area, ashes and fine pyroclastics predominate, with intercalation of coarse grained deposits. The major part of this material has probably been deposited by mud streams and other water related mechanisms during and shortly after the eruptive periods.

Interpretation of the VES reveals a north-south running buried *Basement Ridge* that intercepts this area in its central part. To the west and to the east of this ridge very deep depressions exist with depths exceeding 500 m. The western boundary of the eastern depression is probably fault controlled. Along this inferred fault, the Mua Hills and other in-line craters developed as a product of Holocene volcanism.

Geo-electrically, the western part is characterized by a resistivity of 30 ohmm with intercalations of higher values. On the ridge and in the eastern depression, extreme low resistivities (5-10 ohmm) were found.

Initially, this salient difference was thought to be caused by different groundwater quality. Low resistivity values of this magnitude found on the eastern side generally indicate saline water.

In order to test the VES results, four exploratory boreholes were drilled between Isiolo Town and Shaba Dogo hill along the Garba Tula road . All boreholes were aimed at reaching the basement and exploring the aquiferous properties of the volcanic subsoil.

In the *Area east of the Basement Ridge* C7926 penetrated basement rocks at a depth of 130 m below surface. The outcome of the drilling was rather surprising. Only two relatively thin basalt layers were found, constituting 8% of the total of the volcanic overburden. For the rest, clay and clayey pyroclastic deposits were uncovered with intercalations of clean pyroclastic and gravel layers. The electric resistivity log of the borehole shows resistivity values of 3-6 ohmm for the clayey deposits, which explains the typical low resistivities of the corresponding VES in this area.

In total, 29 m of screens were installed in three different levels below the standing water level of 41 m. From the pumping test, a specific yield of 7.5 $m^3/h/m$ was obtained at a pumping rate of 45 m^3/h, which indicates a safe yield of at least 100 m^3/h. The electric conductivity of the water is 750 $\mu mho/cm^3$.

For this area the following conclusions can be drawn:

(a) the subsoil mainly consists of low resistivity clayey deposits with intercalated thin basalt sheets and clean coarse grained layers.

(b) weathered basalt and clean clastic deposits form high yielding aquifers

(c) the groundwater is of good quality.

(d) the major part of the deposits within this depression probably originated from the Nyambeni volcanic range, mostly because of its close distance to it. Furthermore, the central basement ridge must have functioned as a division between the Mount Kenya and Nyambeni volcanic systems until it was buried by forthgoing deposition from both sides.

In the *Area west of the Basement Ridge* with characteristic resistivity values of 30 ohmm or higher, three boreholes were sunk.

C7924 at the Isiolo airstrip was drilled to a depth of 184 m, without reaching the basement. Over 50% of the penetrated depth consists of basalt and phonolite layers of which some are weathered. The remaining part is mainly clayey pyroclastic.

Two high yielding aquifers were hit in weathered basalt (at 58-66 m and 112-124 m) with an approximate combined output of 30 m^3/h. The E.C. of the mixed water was 11,000 $\mu mho/cm^3$, which is very saline.

During drilling serious problems of caving developed. This prevented the finalization of the borehole and separate testing of the shallower, probably fresh water aquifer. Due to the mentioned drilling problem no electric logging could be done in C7924, hence no relation could be established between VES resistivities and hydrogeological conditions of the deeper strata,

Boreholes C7925 and C7927 were drilled, partly to investigate the extension of the deep saline water body. However both boreholes failed to penetrate unto this depth due to caving and had to be finalized by making use only of the upper, shallow aquifer between 20-30 m. Nonetheless, both wells have a high specific yield of respectively 2.1 and 4.7 $m^3/h/m$ and a good water quality. Both boreholes have a basalt component of about 50%, similar to the one in borehole C7924 at the Isiolo airstrip.

For this area it can be concluded that:

(a) water bearing strata, mostly found in weathered basalt layers, have fresh ground water upto a depth of about 100 m depth and a high yield

(b) deeper aquifers are saline: The areal extension of these aquifers could not be determined with certainty.

(c) Contrary to the eastern area, within this depression a much higher basalt component exists which is reflected by the relatively high resistivities. The major part of the deposits probably originate from the Mount Kenya volcanic belt.

The Southern Nyambeni Plains

This area is situated between the Tharaka Basement Plateau in the south and the higher part of the Nyambeni Range in the north. It is all over scattered with basement hills (inliers). The valleys between these hills were filled up with volcanic material, principally basalts, from the Nyambeni Range. The thickness of the volcanic cover in the valley centre ranges from 50 to 150 m. Characteristic resistivity values are 50 ohmm or higher, indicating a high proportion of basalt components.

Borehole C8977 was drilled at the Birikine Primary School to investigate the aquiferous properties of this area. Basement was found at 66 m below surface. 80% of the volcanic material consists of basalt, which is moderately or strongly weathered at several levels.

Fresh water was struck in weathered basalt at various depths with a high specific yield (11.3 $m^3/h/m$ at a pumping rate of 13 m^3/h).

Most probably, high yield volcanic aquifers can be found anywhere in this area where basalts predominate.

The Eastern Nyambeni Plains

Springs, rivers and around 30 boreholes of Plan International supply water in the southern zone of this area. The boreholes tap mostly the upper part of the first aquifer only, at dephs between 30 and 50 m below surface. More complete information is available from a few deep boreholes.

The zone situated north to the Maua-Meru Park road is completely different. There are no perennial rivers and only very few springs.

The geology of the volcanic deposits shows similarity to that of the Southern Nyambeni Plains with a considerably high basaltic lava component. Groundwater recharge is by precipitation, rivers and underflow in the southern zone and exclusively by underflow in the northern zone. Surface runoff and groundwater flow originate from the Nyambeni Range.

The thickness of the volcanic cover gradually decreases in eastern direction from more than 500 m close to the Nyambeni Range to zero at the volcanic basement contact.

The VES resistivities are similar to those found in the Southern Nyambeni Plains reaching values from 50 ohmm upward. These values indicate a similar consolidated (basalt) and loose (pyroclastic) proportion, which is supported by the existing borehole data.

Two boreholes were drilled north of the Maua-Meru Park road to complement the information already available in the southern area. C9083 at the Ndoleli Primary School with a final depth of 90 m hit several high yielding aquifers in weathered basalt and pyroclastics below 70 m (specific yield 62 $m^3/h/m$, at 9.3 m^3/h pumping rate). C9084 in the Maraeni area with a depth of 120 m, gave a specific yield of 16,4 $m^3/h/m$ under similar conditions. Both wells produce fresh groundwater with an EC of approximately 400 $\mu mho/cm^3$. The basalt/pyroclastic relation in these boreholes is 40/60% and 70/30% respectively.

4 HYDROLOGY

4.1 Introduction

This chapter provides a brief description of the results of hydrological investigations in Meru District. The hydrological studies are necessary for the analysis of the surface water and groundwater potential in the District.

The District, covering an area of 9,922 km^2, shows strong contrasts in climatic conditions. The Mount Kenya area to the west receives heavy rainfall of upto 2100 mm, the Nyambeni Hills to the north get over 2000 mm while the Tharaka area to the south-east receives only about 700 mm. Evaporation figures are lowest in mountainous areas (about 1500mm) and highest in rainfall deficient low lying areas of Tharaka (about 2500mm).

The mountainous areas of Mount Kenya and Nyambeni Hills are heavily forested and form the most productive parts of the district. They are also the source areas of the perennial streams and rivers. The flows of streams and springs provide insight into the regimes of both surface and groundwater. Hence for proper management of these streams and exploitation of the surface and groundwater resources, analysis of the discharges and storage capacity (groundwater systems) is of paramount importance. Especially important are the statistics on the reliability of these resources in periods of droughts.

4.2 Previous Studies

Scanty information on hydrology of some parts of the district is found in a few irrigation reports but only one report merits to be mentioned.

The Thanantu Valley Irrigation Project - Feasibility Study 1979. This report is in seven volumes of which volume III is Hydrology. The aim of the Thanantu feasibility study was to make proposals for the development of the Valley for irrigated agriculture using the stream flow of Kathita, Thangatha and Ura rivers. The project is located some 30km east of Meru municipality astride Thanantu river and covers a gross area of about 60 km^2. The hydrology study of the area includes an inventory and analysis of 18 river gauging stations (RGS) and 20 rainfall stations in the sub-catchment area of 4F. The data for 7 RGS and 8 rainfall stations were processed and analysed for irrigation planning and appraisal.

4.3 Hydrometeorological Network

The district is fairly well covered by hydrometeorological stations except for the semi-arid areas of Meru National Park and the Northern Grazing Area which are nomadically inhabited (Plate 4.1).

Rainfall Network

There are about 123 standard raingauges, 90 of which are in operation while 33 are closed. Most of these belong to Kenya Meteorological Department (KMD) while the rest are operated by Ministry of Water Development (MoWD). These two agencies collect, store and exchange the data.

The oldest rainfall stations are found at Meru D.C. (1910), Igoji mission and Mujwa catholic mission (1915).

High altitude storage raingauges exist on Mount Kenya. These are located along the Sirimon Track near Nanyuki, the Kisima Track near Kisima area and along the Chogoria Track. These gauges were installed to monitor rainfall in the altitude range between 2,350 and 4,100 m. Readings are usually taken with a dip stick once every 3 months but this interval may change if there are transport problems. Only 4 raingauges along the Chogoria Track are still in operation since 1959.

The majority of the rainfall stations were visited by WRAP in February 1988 when old raingauges were either replaced or rehabilitated.

Rainfall station details and the available records are shown in Appendix 4.1. Discontinuities in data records are mainly due to negligence of raingauges by observers.

Evaporation Network

The district has 9 evaporation pans, 7 of which are in operation while 2 are closed. The Maua and Chuka pans were installed by WRAP in March 1988.

Evaporation records started in 1948 at Tana Grand Falls followed by Meru Water Supply in 1952. Evaporation data are collected and stored by both KMD and MoWD.

Evaporation station details and bar graphs of available records are in Appendix 4.2.

Meteorological Stations

These exist at Kaaga, Marimanti and Mariene. Apart from rainfall and evaporation observations, they have additional instruments for the monitoring of temperature, radiation, sunshine, wind speed and direction, humidity etc. They were established in 1966, 1965 and 1960 and operated by KMD, MOWD and Coffee Research Foundation respectively.

River Gauging Stations (RGSs)

A total of 83 RGSs have been constracted, 47 of which are still in operation while 36 have been closed for various reasons. Out of the 47 operational stations, 8 are operated from Nanyuki, 28 from Meru and 11 from Embu water offices. The Nanyuki office monitors those stations in drainage area 5 except 5D14 which is under Meru. The Embu office monitors stations in the minor sub-catchment area of 4EB, and the lower part of 4EA.

There are 6 operational water level recorders, 5 of which are on the Timau side and were installed and operated by ASAL in Nanyuki while the sixth recorder is on Tana river at Grand Falls. 4 recorders are unoperational due to various reasons ranging

from lack of charts at Mutonga 4EA7 to poor security and accessibility at Rojewero 4F18, and Tana, Adams Falls 4F16. The recorder at Kathita 4F19 is unoperational due to vandalism.

Most of the RGSs have staff gauges on them and only those in drainage area 5 have weirs as a form of control. WRAP has rehabilitated 10 RGSs by the installation of 1st, 2nd and/or 3rd gauge(s) where they were washed away by floods.

Runoff records are collected and stored by MoWD and date back to 1931 on three streams on Timau side of the Mount Kenya. On the Meru side, water level observations started in 1948 at Kathita 4F2 while most of the stations were established in 1952 and afterwards.

Station details and bar-graphs of the available records are shown in Appendix 4.3.

Monitoring of Surface Water Quality

Water quality monitoring is usually done when there is need to investigate a water supply source for potability or investigate the extent of coffee waste pollution to rivers. There is thus no regular sampling network established.

4.4 Rainfall

4.4.1 Relation Between Rainfall and Topography

In general, rainfall increases with increasing altitude. The distribution of rainfall in the district is strongly influenced by the presence of Nyambeni Hills to the northeast and Mount Kenya to the west. These mountain ranges act as wind barriers to the moisture bearing southeast and the northeast monsoons forcing the humid air to rise. As a result, the windward southern and eastern slopes of the Nyambeni Hills and the windward eastern slopes of Mount Kenya receive heavy rainfall whereas the leeward northern Nyambeni and western and northern Mount Kenya slopes receive low rainfall.

4.4.2 Seasonal Rainfall

The mean monthly rainfall distribution in the district is shown in Table 4.1 which contains 16 selected stations. March-May and October-December are the rainy seasons with long rains and short rains respectively. June-September are the driest months. April and November are generally the wettest months receiving between 20-30% of annual rainfall each (Figure 4.1).

Table 4.2 summarises the seasonal rainfall distribution from which it can be seen that about 90% of the annual rainfall falls during the two seasons in most parts of the district. The situation is however different on the Timau side where the two main seasons contribute about 63% while the continental rains (June-August) contribute about 27% of the annual rainfall.

The long rains are brought about by the south-east monsoons which are heavily laden with moisture from the Indian Ocean. When these winds enter the district they are forced to rise by the physical barriers on their way i.e the Nyambeni Hills and Mount

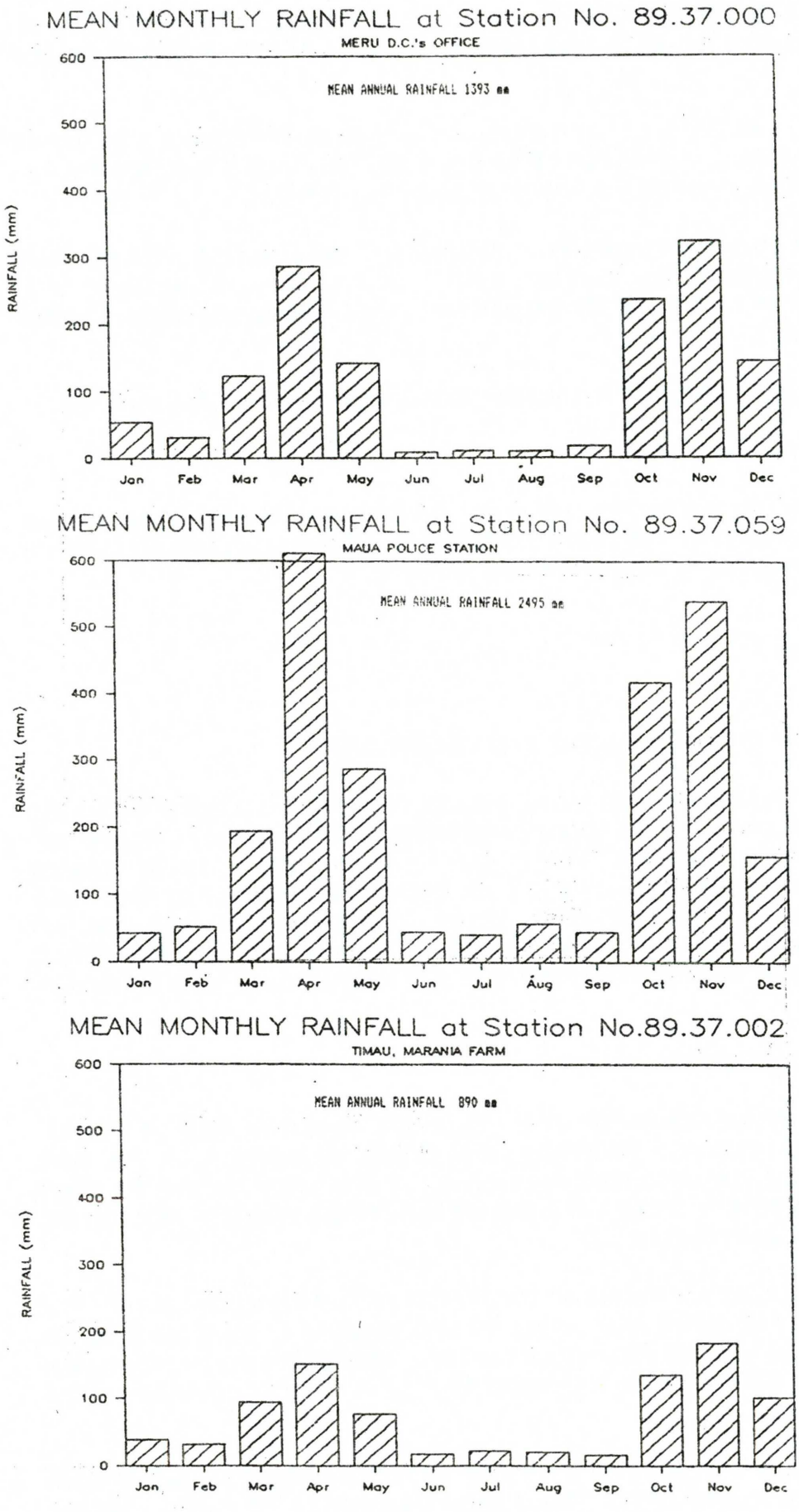


Fig. 4.1 Mean Monthly Rainfall Distribution Patterns

Table 4.1 Mean Monthly Rainfall Distribution (mm)

Station Name and Number	Period of Record	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Eastern Slopes of Mt. Kenya														
Meru D.C 89.37.000	1910-1971 No data 1911-13	54	31	123	286	143	9	11	11	19	237	323	145	1393
Chuka 90.37.034	1939-85 No data 1967-71	49	39	128	385	167	18	29	27	27	202	329	116	1515
Kionyo 90.37.189	1974-85	53	76	188	464	218	22	15	11	23	245	367	174	1855
Northern Slopes of Mt. Kenya														
Marania 89.37.002	1925-85	39	33	95	152	77	17	22	20	16	135	183	102	890
Ardencaple 89.37.034	1948-85	13	14	42	107	98	50	52	68	33	66	73	29	644
Sirimon Gate 90.37.155	1970-85	32	24	53	142	187	81	90	101	69	110	130	39	1058
Northern Grazing Area														
Isiolo D.C. 89.37.003	1930-86	35	37	84	122	33	5	5	5	7	64	147	76	618
Liliaba 89.37.090	1974-84	28	2	74	203	69	4	7	1	4	68	171	43	674
Southern Slopes of Nyambeni Hills														
Mikinduri 89.37.014	1937-85 No data 1965-72	51	34	161	469	201	13	11	13	17	285	419	203	1877
Eastern Slopes of Nyambeni Hills														
Maua 89.37.059	1959-85	43	52	195	610	287	45	42	58	45	419	541	158	2495
Kathanga 89.37.089	1974-84	56	10	108	363	131	22	31	26	36	202	355	141	1480
Meru National Park - Kinna Area														
Kinna 89.38.001	1972-86	15	7	28	105	29	0	0	0	1	79	121	66	452
Ura Gate 89.38.007	1980-85	5	4	67	204	53	4	0	1	2	177	130	73	719
Mitunguu Area														
Mitunguu 90.37.085	1949-85	37	30	127	331	136	10	16	8	10	205	340	123	1370
Tharaka Area														
Marimanti 90.37.160	1965-85	30	25	83	264	83	6	2	2	5	88	213	71	870
Thuchi 90.37.230	1964-87	30	26	99	189	39	9	2	1	5	94	217	76	786

Kenya and they shed most of their load of moisture on the windward sides of these barriers. As such the southern and eastern slopes of the Nyambeni Hills and the eastern slopes of Mount Kenya receive heavy amounts of the long rains.

Table 4.2 Mean Seasonal Rainfall Distribution

Station Name and Number	Long Rains (March-May)		Short Rains (Oct-Dec)		Continental Rains (June-Aug)		Annual Total
	%	mm	%	mm	%	mm	mm
Eastern Slopes of Mount Kenya							
Meru D.C's Office 89.37.000	40	557	50	697	2	31	1393
Chuka Chief's Office 90.37.034	44	667	43	651	5	73	1515
Kionyo Dispensary 90.37.189	47	872	42	779	3	48	1855
Northern Slopes of Mount Kenya							
Marania Farm 89.37.002	37	329	47	418	6	53	890
Ardencaple Farm 89.37.034	38	245	25	161	27	174	644
Sirimon Gate 90.37.155	36	381	26	275	27	286	1058
Northern Grazing Area							
Isiolo D.C's Office 89.37.003	39	241	46	284	2	14	618
Liliaba Assistant Chief 89.37.090	51	344	41	276	2	15	674
Southern Slopes of Nyambeni Hills							
Mikinduri Primary School 89.37.014	45	845	48	901	2	38	1877
Eastern Slopes of Nyambeni Hills							
Maua Police 89.37.059	44	1098	45	1123	6	145	2495
Kathanga Primary School 89.37.089	41	607	48	710	6	94	1480
Meru National Park - Kinna Area							
Kinna Scheme 89.38.001	35	158	60	271	0	1	452
Ura Gate 89.38.007	44	316	53	381			719
Mitunguu Area							
Mitunguu Tree Nursery 90.37.085	43	589	49	671	3	44	1370
Tharaka Area							
Marimanti Met Station 90.37.160	49	426	42	365	1	10	870
Thuchi Barrier 90.37.230	42	330	50	393	1	10	786

The north-east monsoons collect their moisture from the Indian Ocean and the Indian sub-continent. Their effect to the district is similar to that of the south-east monsoons and they equally contribute large amounts of seasonal rainfall. The two seasons in fact contribute about equal amounts of rainfall with the short rains contributing slightly more (45%) than the long rains (42%) on average.

The continental rains are as a result of convective activity over the land area and the moisture bearing winds originate from the Congo basin and Lake Victoria to the west. These rains are effective in the western and north western slopes of Mount Kenya i.e the Timau-Nanyuki area to the west of the district.
The seasonal rainfall distribution is shown in Figures 4.2 and 4.3 for the long rains and the short rains respectively. It can be seen that the distribution of rainfall in the two seasons is basically similar with high rainfall concentration in the Nyambeni Hills and the area near the forest edge on the eastern slopes of Mount Kenya stretching roughly from Kiamuriuki Forest Guard's Post through Chogoria Forest Station, Marimba Livestock Farm to Katheri.

The short rains however generate heavier storms than the long rains. Over the Nyambeni Hills, three stations recorded over 1000 mm while only one station recorded slightly over 1000 mm on Mount Kenya area during the short rains. Two stations on Nyambeni Hills recorded over 1000 mm during the long rains but none on Mount Kenya. Away from these physiographic features, rainfall decreases gradually to the north of Mount Kenya and to the northern, eastern and southern Nyambeni Hills.

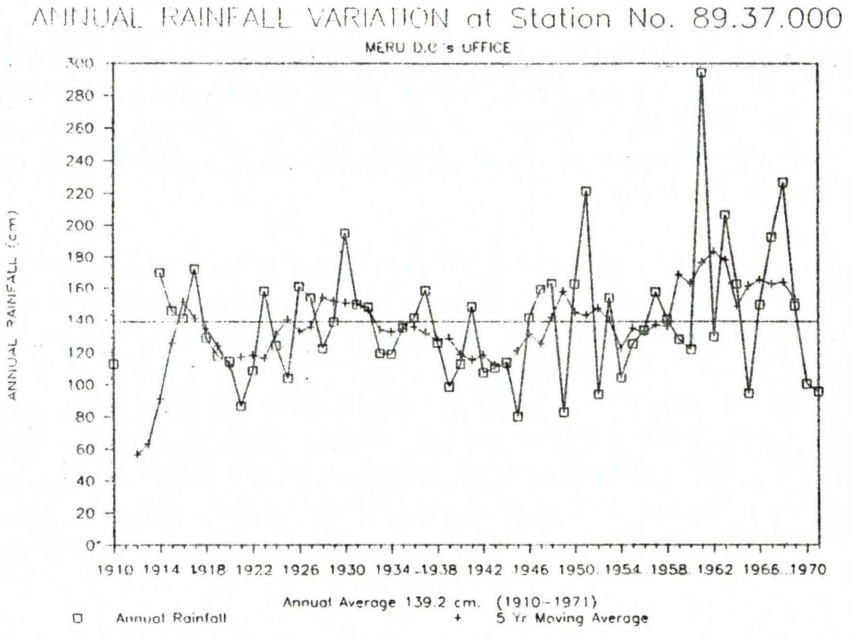
There is also a gradual decrease in rainfall on Mount Kenya as one moves from the forest edge to the top of the mountain as recorded by the storage longterm high altitude raingauges. This is because the moisture laiden winds are forced by the high ground near the forest edge to rise and thus shed most of their heavy loads lower down the mountain before they reach the top, and as a result the areas after the forest edge or the tea zone receive fairly low rainfall amounts which decrease as the altitude increases.

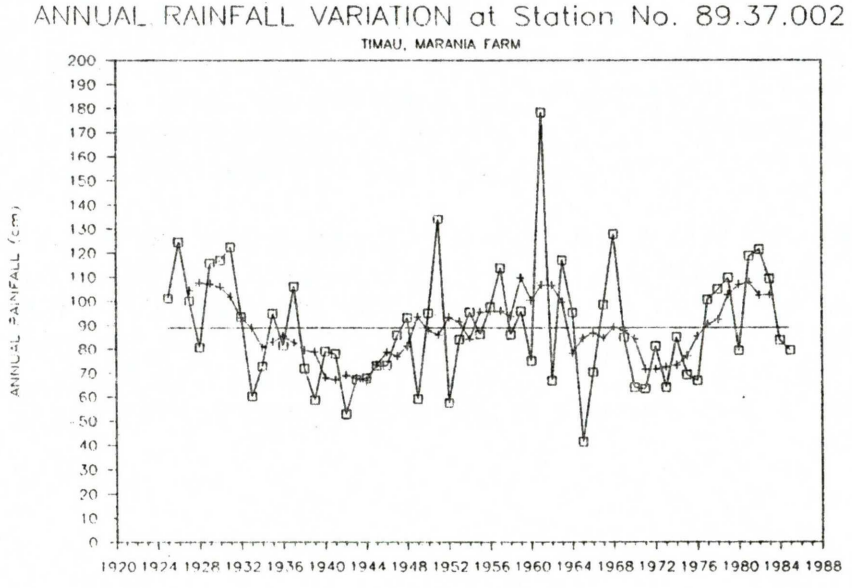
4.4.3 Annual Rainfall

The distribution of annual rainfall is shown by the isohyetal map Figure 4.4. The distribution is very similar to the seasonal rainfall distribution already discussed. A tongue of high rainfall concentration stretches from Kiamuriuki Forest Guards Post (1706 mm), through Chogoria Forest Station (2033 mm), Kionyo (1855 mm), Marimba (2107 mm), to Katheri (1810 mm) on the eastern slopes of Mount Kenya. On either side of this tongue, there is a gradual decrease in annual rainfall to about 900 mm near the top of Mount Kenya and about 800 mm along the Ishiara - Chiokarige road.

On the leeward side of Mount Kenya i.e the Marania-Timau area, annual rainfall is between 600 and 800 mm.

The Nyambeni Hills experiences the highest concentration of annual rainfall. The Mikinduri, Michimukuru, Maua, Akachiu and Lare areas receive over 2000 mm with Maua topping up with 2500 mm. Away from the Hills, rainfall decreases with decreasing altitude. Annual rainfall in Tharaka and Meru National Park areas ranges from about 600 - 800 mm while in the Meru Concessional and Northern Grazing Areas is between 500 and 800 mm.





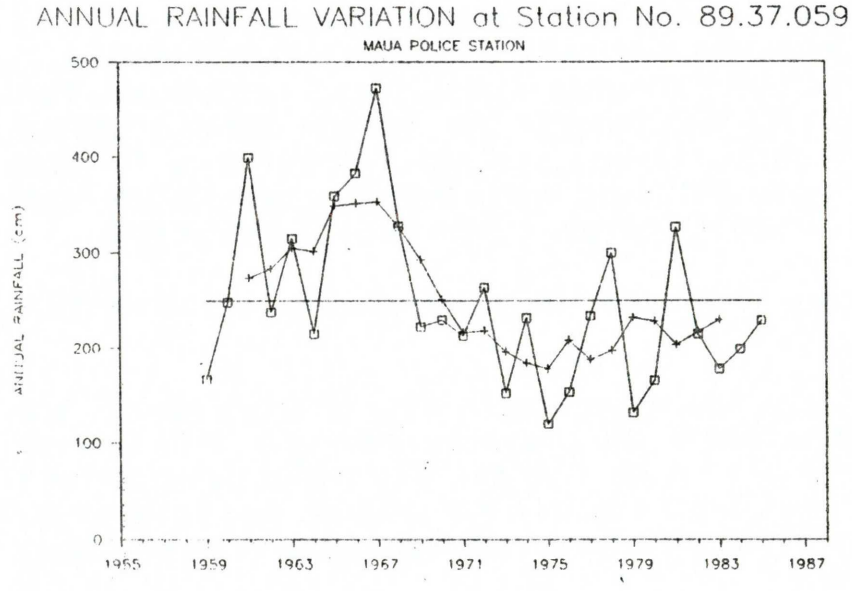


Fig. 4.2 Trends of Annual Rainfall

In between Mount Kenya and Nyambeni Hills, there is a tongue of low rainfall in the Ruiri area where annual rainfall is about 800 mm. This rainfall decreases northwards to about 600 mm at Isiolo.

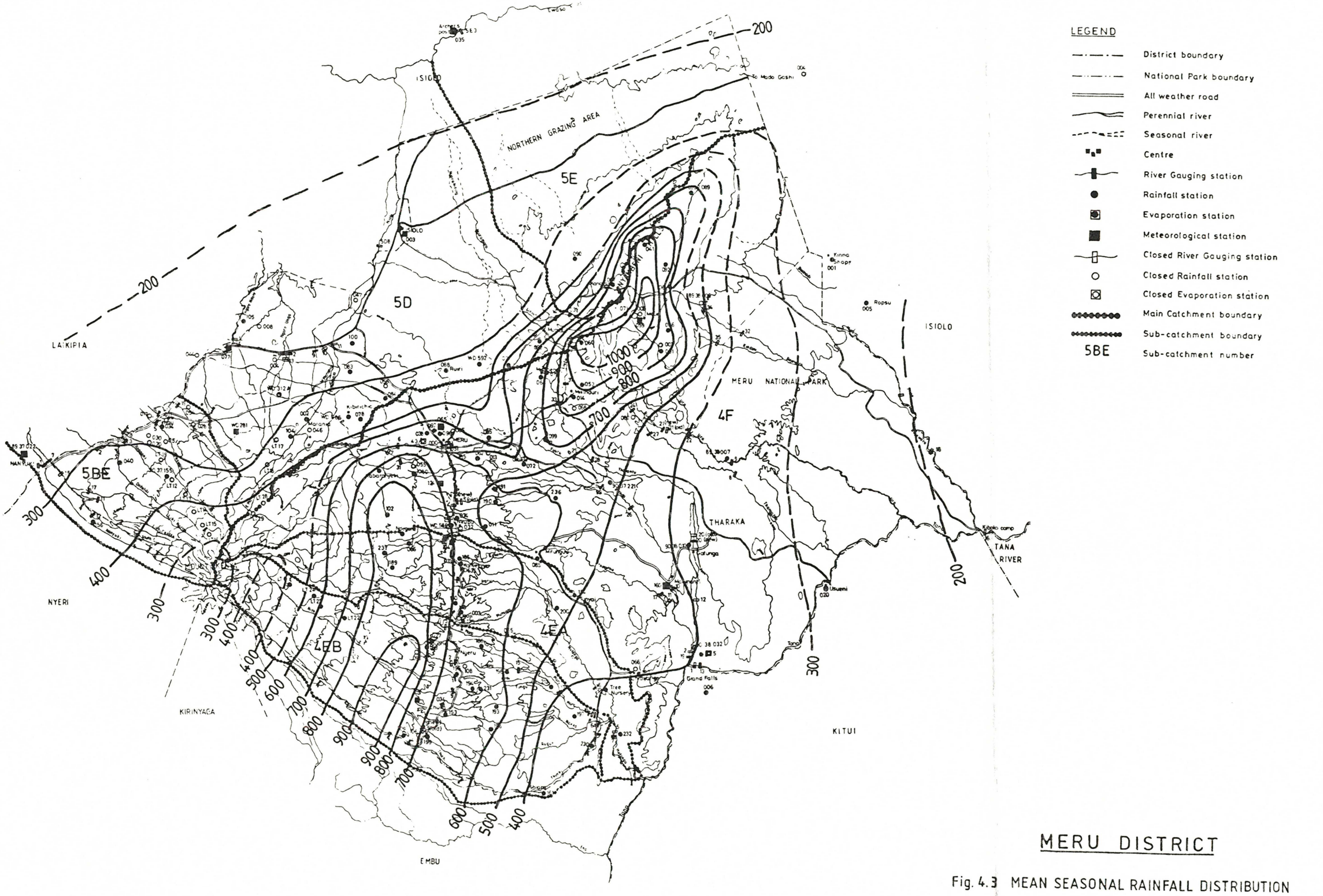
The trends of annual rainfall have been obtained by fitting a 5-year moving average line over the annual rainfall data and thus damping out the yearly fluctuations. The trends of three rainfall stations are shown in Figure 4.5.

The Marania farm on the northern slopes of Mount Kenya show that annual rainfall was above average during the twenties, below average in the thirties and forties, average in the late forties upto early fifties, above average in the late fifties upto early sixties, below average afterwards upto 1976 and thereafter above average upto 1984.

At Meru on the eastern slopes of Mount Kenya the conditions were slightly different in that early twenties was a dry period with rainfall below average while the sixties was a wet period.

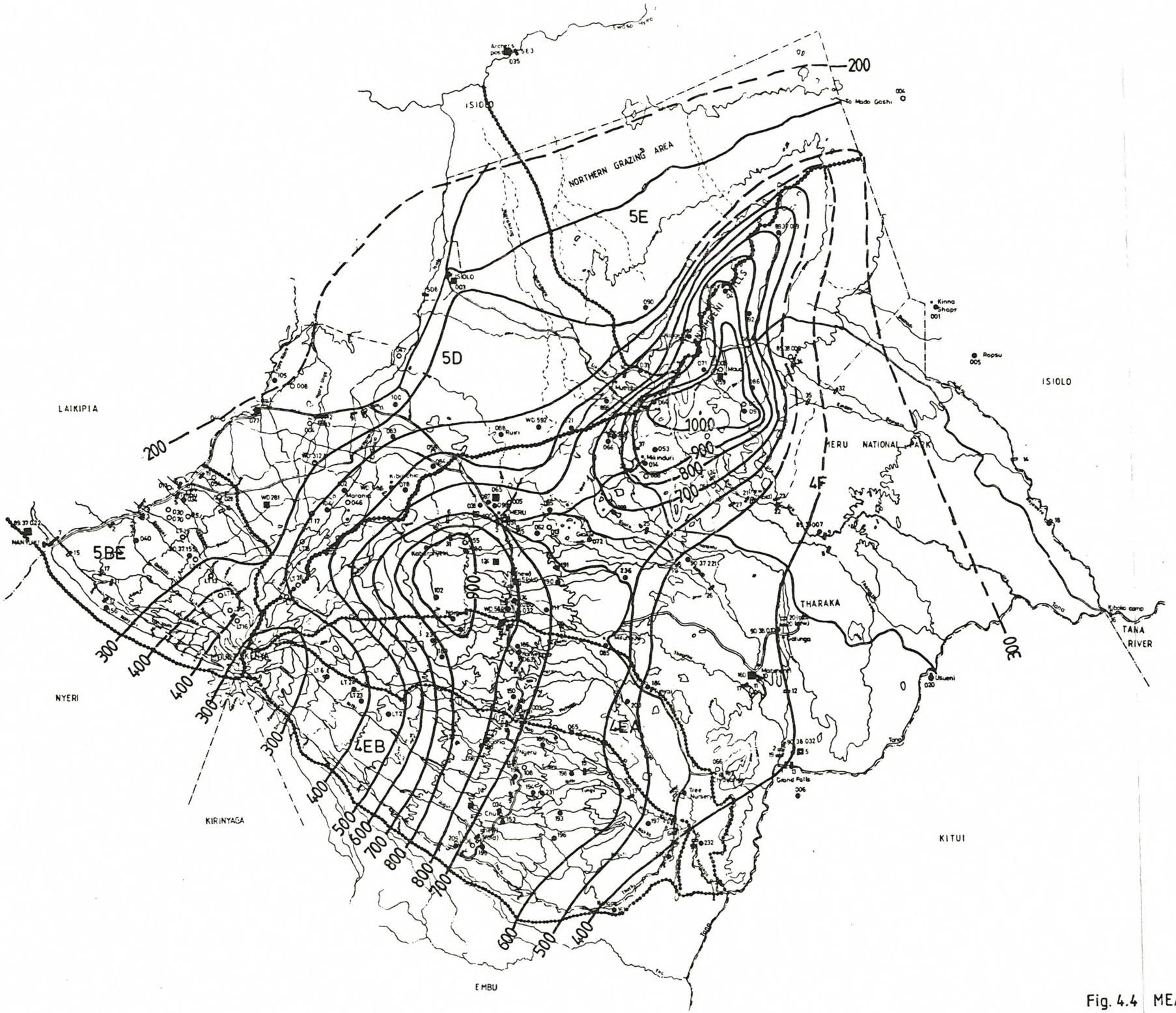
On the eastern slopes of Nyambeni Hills, the Maua station shows the sixties as a wet period and the seventies and eighties as a dry period in which rainfall was below average. One will however note that during this "dry" period, rainfall was above 1300 mm as the annual average is about 2500 mm.

Appendix 4.4 contains more rainfall variation figures.



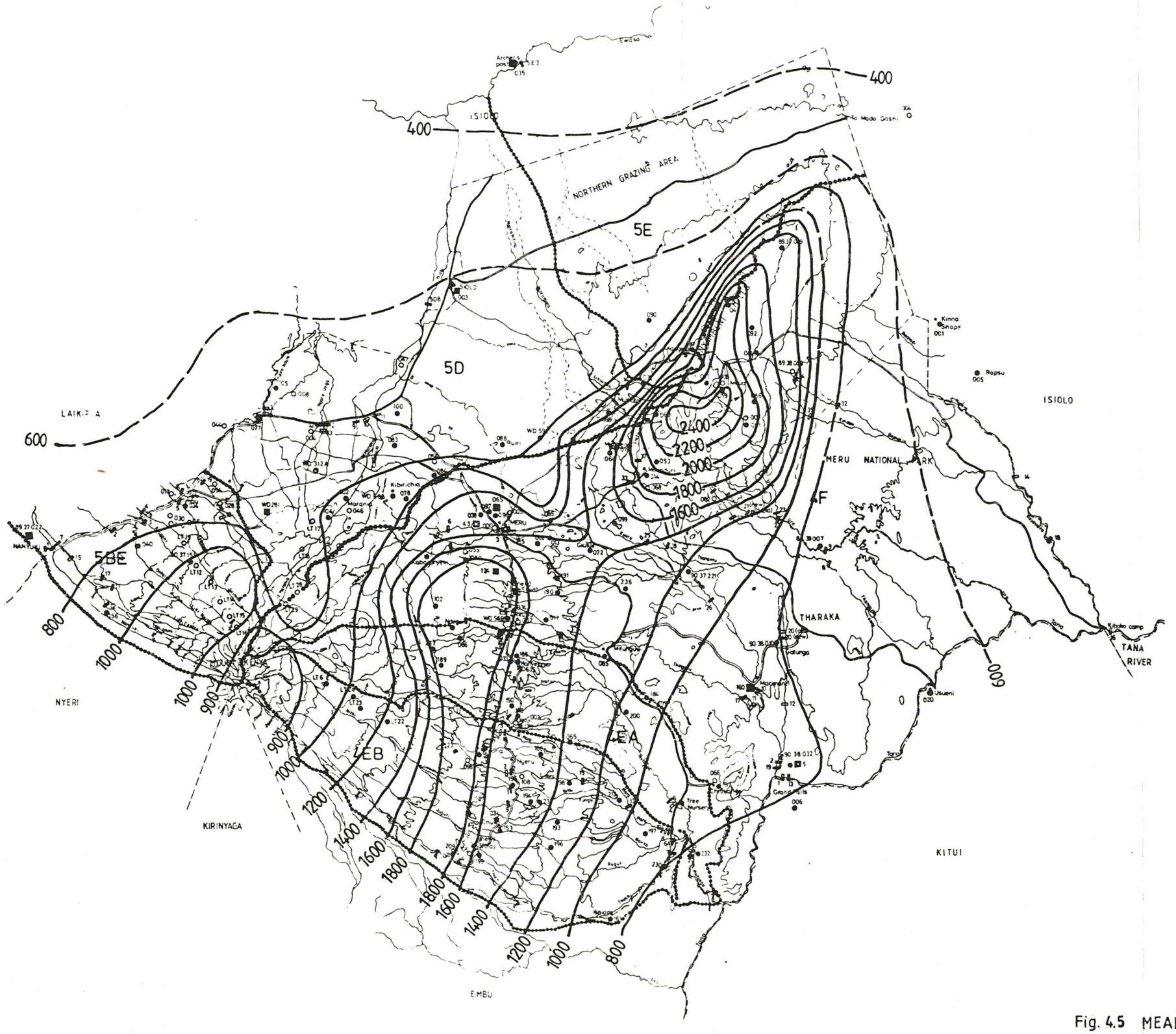
MERU DISTRICT

Fig. 4.3 MEAN SEASONAL RAINFALL DISTRIBUTION
(March – May)



MERU DISTRICT

Fig. 4.4 MEAN SEASONAL RAINFALL DISTRIBUTION
(Oct. – Dec.)



MERU DISTRICT

Fig. 4.5 MEAN ANNUAL RAINFALL DISTRIBUTION

4.5 Evaporation

4.5.1 Relation Between Evaporation and Topography

Evaporation data is mainly essential in water balance studies, in the design of water reservoirs for irrigation and hydropower generation and in the determination of the consumptive use of crops in irrigation design.

Evaporation rates vary with the altitude of an area and normally decrease with increasing altitude. The altitude dependence of annual pan evaporation in the area is given by the following regression equation:

Annual pan evaporation Ep (mm) = 2955 - 0.963 Altitude (m)

The standard error of the evaporation is estimate = 123 mm.

The negative correlation between evaporation and altitude is shown in Figure 4.6 where Embori plots way out of the other stations and thus the regression equation is not applicable to that area. Embori Farm on the northern slopes of Mount Kenya has an evaporation rate similar to that of the other five stations on the eastern slopes, although it's altitude is much higher. This is caused by the climatic conditions on the northern side of Mount Kenya being cooler and less wet than on the eastern side.

4.5.2 Monthly Evaporation

Table 4.3 gives mean monthly evaporation rates as recorded in nine evaporation stations. It can be seen that the hottest months are February-March in the Timau area and September-October in the rest of the district when the evaporation rates are the highest. In most stations the months of June-August are the coolest since evaporation rates are at their lowest. For the semi-arid Tharaka area, May-June and November-December are the coolest months (Figure 4.7).

Putting these figures on a daily basis, the daily evaporation rates in the district varies from a cool 3.0 mm at the high altitude stations to a high 8.2 mm in Tharaka area.

The months of low evaporation rates experience cloudy skies which suppress temperatures and radiation - the two main factors which govern high evaporation rates.

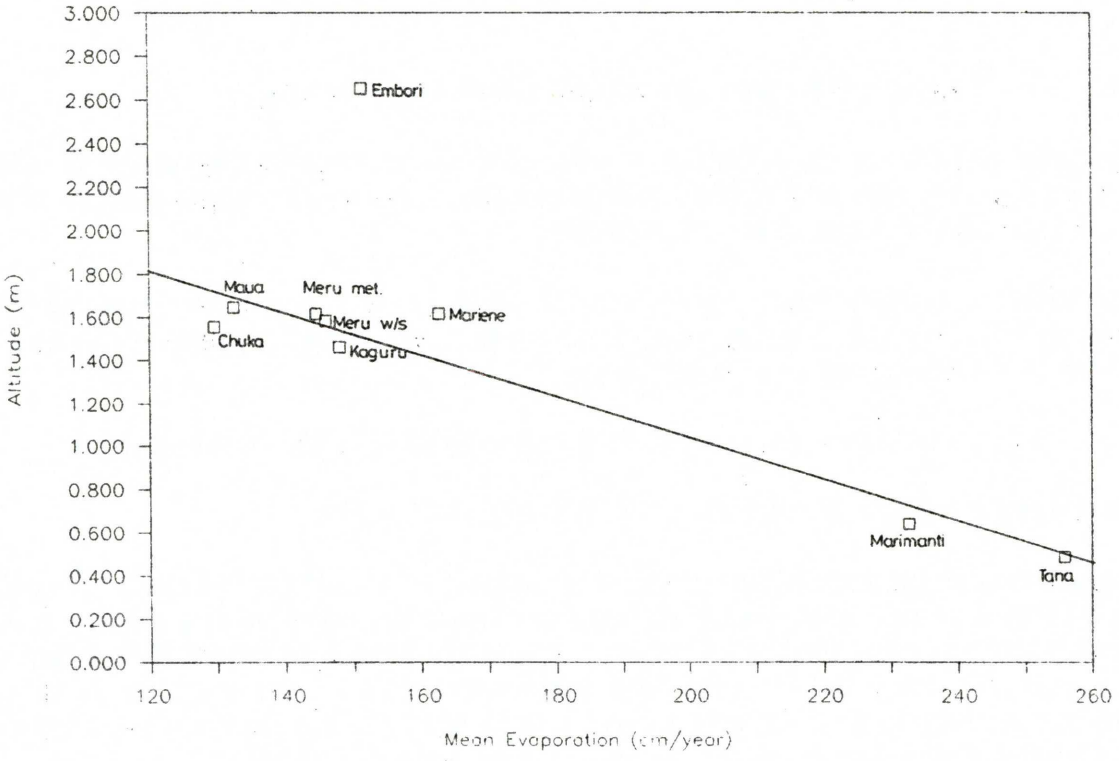


Fig. 4.6 Evaporation-Altitude Correlation

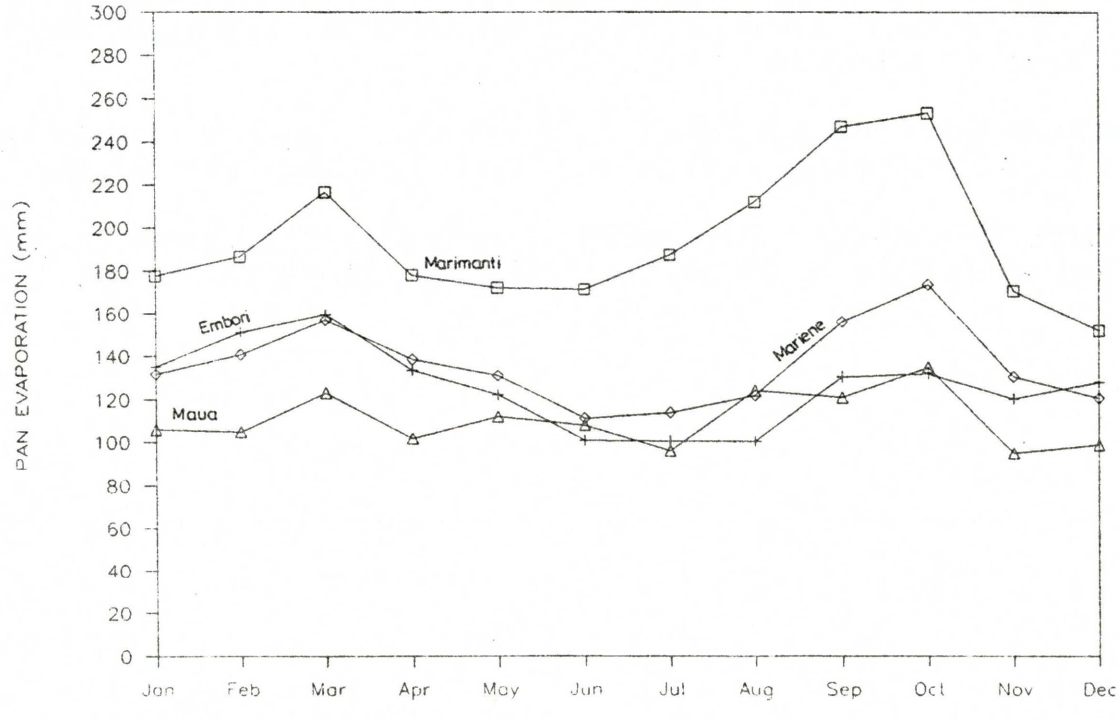


Fig. 4.7 Mean Monthly Pan Evaporation

Table 4.3 Mean Monthly Pan Evaporation Rates in mm

Evaporation Station and Period of Record	Altitude (m)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Northern Slopes of Mt. Kenya														
*Embori Farm 1985-89	2652	144	148	153	135	132	107	99	106	129	129	122	133	1537
Eastern Slopes of Mt. Kenya														
Meru Met Station 1976-89	1616	119	123	144	113	114	98	100	119	137	154	108	105	1433
Meru Water Supply 1952-75	1585	124	131	141	123	121	105	101	106	138	151	112	110	1461
Kaguru F.T.C 1976-89	1463	127	134	148	114	113	102	100	113	146	148	111	110	1468
Mariene C.R.F 1960-89	1616	132	141	157	136	130	111	112	122	155	174	130	121	1620
*Chuka Forest 1988-89	1555	105	100	141	126	116	92	80	90	112	128	114	93	1297
Tharaka Area														
Marimanti Met Station 1965-89	640	180	190	217	178	172	173	187	210	246	253	170	151	2326
Tana Grand Falls 1948-64	488	197	220	232	183	204	212	221	239	250	253	188	160	2559
South Eastern Slopes of Nyambeni Hills														
*Maua D.O 1988-89	1646	106	105	123	102	112	108	96	124	121	135	95	99	1,326

*Longterm mean monthly evaporation rates have been extrapolated using Mariene C.R.F. record.

4.5.3 Comparison of Pan Evaporation, Potential Evaporation and Evapotranspiration

T. Woodhead studied rates of evaporation from open water surfaces in Kenya (1968) using the Penman method and derived the following regression equation:

$$Eo = 2422 - 0.358\ h$$

$$r^2 = 0.66$$
$$n = 78$$

where Eo = open water evaporation in mm

h = altitude in metres above mean sea level.

J. Kalders of the Ministry of Water Development's Irrigation Section has also made studies of potential evapotranspiration (ET_o) in Kenya (September 1988) and derived the following regression equation:

$$ET_o = 2532 - 0.441\ h$$

$$r^2 = 0.55$$
$$n = 84$$

where ET_o = annual potential evapotranspiration in mm

h = altitude above mean sea level in metres

Using the measured pan evaporation data and estimates computed from the above two equations, a comparison of pan evaporation (Ep), potential evaporation (Eo) and potential evapotranspiration (ET_o) is made in Table 4.4 for a few selected stations.

Table 4.4 Comparison of Annual Evaporation Rates and Rainfall (mm)

Station	Altitude m	Rainfall	Measured Ep	Calculated	
				Eo	ETo
Embori Farm	2652	709	1537	1473	1363
Maua	1646	2495	1326	1833	1806
Meru Met	1616	1273	1433	1843	1820
Chuka Forest	1555	1708	1297	1865	1847
Marimanti	640	870	2326	2193	2250

It is very clear from the above table that open water evaporation rates are very close to potential evapotranspiration estimates. Pan estimates for Maua, Meru and Chuka are much lower than either Eo or ET_o values. This is because in cool and wet climates the pan tends to underestimate evaporation while in hot and dry climates, it tends to overestimate.

4.5.4 Comparison of Mean Monthly Rainfall and Pan Evaporation

A comparison of measured rainfall and pan evaporation at Meru Meteorological Station, Embori Farm and Marimanti Met Station shows that while Meru has a lot of surplus water during the rainy seasons, Embori has none at all and only small amounts are available at Marimanti. However, actual evapotranspiration figures are much lower than the pan estimates as the former depend on the supply of moisture. Hence in real life, surplus rain does occur at Embori and Marimanti during the rainy seasons.

Appendix 4.5 shows these comparisons as discussed above.

4.6 Surface Runoff

4.6.1 General

Most of Meru District is well drained by springs, streams and rivers, except for the Meru Concessional and the Northern Grazing Areas to the north and north-east of Nyambeni Hills.

The Mount Kenya to the east and the Nyambeni Hills to the west of the district are the two major physiographic features which influence the drainage pattern (Plate 4.1).

The drainage system in the district can be divided into two parts. The northern part of the district comprising the Timau, Marania, Isiolo and Northern Grazing areas, drain to the Ewaso Ng'iro River and forms part of drainage area 5. The southern part of the

district belongs to the Tana River basin (drainage area 4). In terms of runoff generation, this is the most important part as it also receives heavy rainfall amounts.

4.6.2 Ewaso Ng'iro Drainage System

The springs, streams and rivers flowing to the Ewaso Ng'iro River are fairly small as they drain the leeward side of the Mount Kenya and Nyambeni Hills.

The streams draining the sub-catchment area of 5BE i.e those in the Timau - Nanyuki area carry substantial flows as they originate from high up in the Mount Kenya forest where rainfall is over 1000 mm per year. These streams include Liki, Ontulili, Teleswani and Timau.

The 5D sub-drainage area has only a few spring discharges which collect together to form rivers Engare Ndare and Isiolo. The origin of these springs is way down the slopes of Mount Kenya where rainfall is less than 1000 mm per year. Towards Isiolo town, there is no perrennial flow.

The Likiundu stream, which originates from Nyambeni Hills, barely reaches the Isiolo - Garba Tula road as it seeps into the dry sandy bed.

The 5E sub-drainage area covers the Meru Concessional and Northern Grazing areas to the north of Nyambeni Hills. Most of this area receives rainfall in the range 400-700 mm per year and this lack of enough moisture means that there is absolutely no perrennial flow. The existing dry lagas carry runoff only during the rains.

The Ewaso Ng'iro drainage system was part of the Water Resources Assessment Study in Laikipia District and is covered by the May 1987 report.

4.6.3 The Tana River Drainage System

This is the most important part of the district in terms of runoff generation, rainfall input and agricultural and commercial activities. The area is in the windward side of the mountain ranges that control the moisture laiden winds and thus receives fairly heavy rainfall amounts. This leads to the creation of a dense drainage network especially on the slopes of the two mountain ranges and consequent formation of fairly large rivers like the Mutonga and Kathita.

Rainfall over the slopes of Mount Kenya ranges from 1400 - 2100 mm per annum while over Nyambeni Hills, it is between 1800 and 2500 mm. Most of the annual rainfall falls in April-May and November-December months and these are the same months when high water levels are encountered. Floods generated from Nyambeni Hills are much higher, faster and more severe as the catchment areas of Ura and Thangatha are fairly small and steep.

For a description of the ten relatively big rivers in this drainage system, most of which are tributaries of the Mutonga and Kathita rivers (see Appendix 4.6).

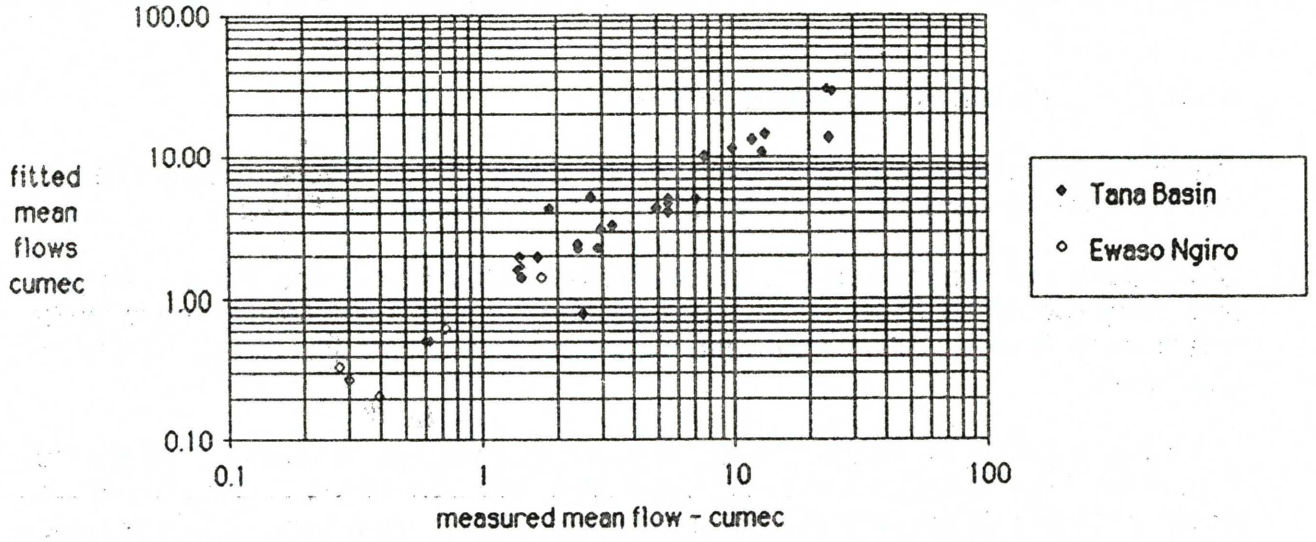


Figure 4.8 Mean Flow Related to Catchment Size and Mean Rainfall

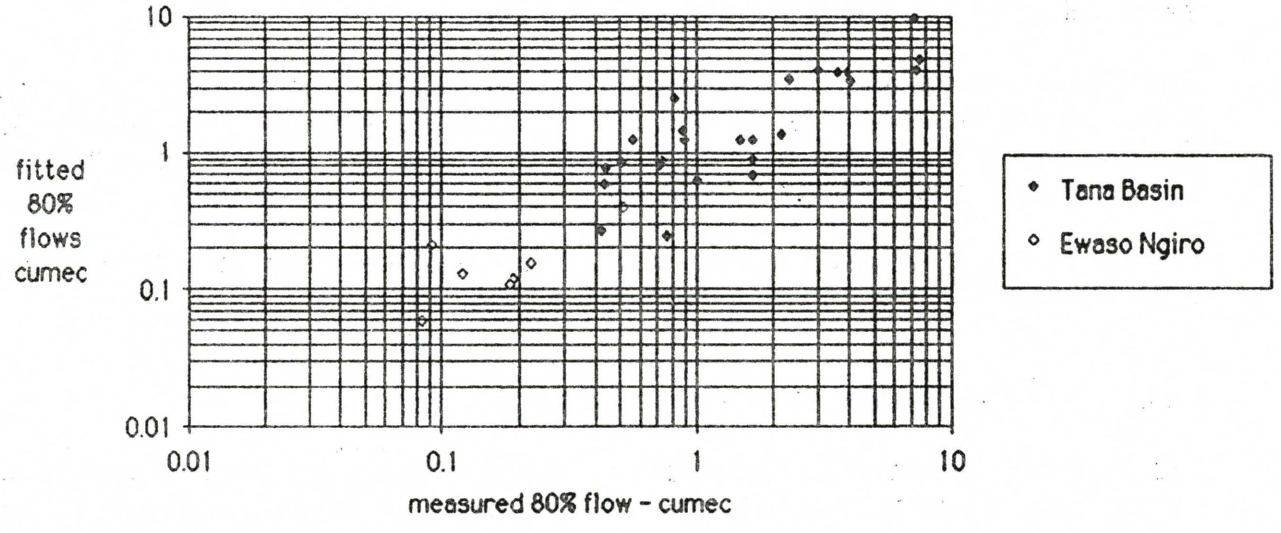


Figure 4.9 96% Flow Related to Catchment Size and Mean Rainfall

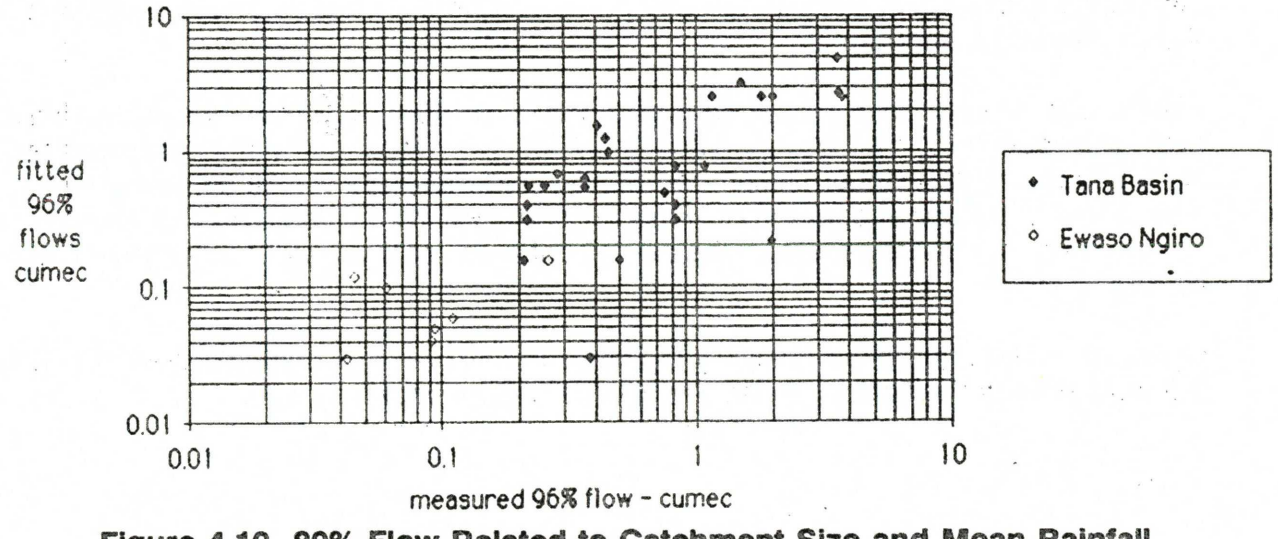


Figure 4.10 80% Flow Related to Catchment Size and Mean Rainfall

4.7 Streamflow Related to Catchment Size and Precipitation

4.7.1 General

Prediction of streamflow is important for proper water resources planning in ungauged catchment. The 96% flow is used as a design criterium for domestic supplies, the 80% flow for irrigation. In addition, planners are also interested in mean flows. In the following paragraphs these flow rates will be correlated to two readily available parameters, i.e the drainage area and the mean annual rainfall.

4.7.2 Available Data

Data for 50 Regular Gauging Station (RGS) in Meru, Laikipia, Baringo and Isiolo have been processed by the Water Resources Assessment and Planning Project. The data of six stations look suspicious: 4EA1, 4EB4 and 4EB16 because the run-off co-efficient is higher than 80% (this is highly unlikely for Kenyan conditions) and 4EA4, 4EF3 and 2F21 because their baseflow recessions are so irregular that the quality of their records is dubious. The data of these stations were not used in the analysis.

Of the remaining 44 stations, 6 are situated in Baringo (drainage area 2), 16 in Laikipia and 1 is Isiolo (drainage area 5). The remaining 21 are tributaries of the Tana River situated in Meru District (drainage area 4). For each station there is a streamflow data book containing i.a daily, monthly and annual flows, and frequency distributions of the daily flows. These frequency distributions were used to estimate the 50%, the 80% and the 96% flows (the x% flow is the flow rate which is equaled or exceeded in x% of the time). The mean flow is simply the arithmetic mean of all daily readings.

Catchment areas are given in the streamflow data books. Mean annual rainfalls were estimated using the isohyetal maps prepared for the Water Resources Assessment Studies of Baringo, Laikipia and Meru.

The data were used as they are: no attempts were made to correct them for abstractions. This is because too little is known about the real dry season abstractions: much is done illegally. Nevertheless, proper information about the actual diversions will lead to much improved estimates of dry season flows. Adequate information on dry season abstractions could improve the relationship considerably. Drought flows from small catchments are particularly influenced by major diversions and/or the presence of major springs. As a result the residual variance is for small basins much greater than for large ones.

4.7.3 Analysis and Results

Power equations were derived by multiple regression of the logarithms of streamflow on catchment area and mean annual rainfall. The exponents of the regression equations for the mean and 80% flow are very similar. So, it was decided to neglect the differences. These equations performed also well on the 96% flows. Data plots (measured values against the fitted values) are given in Figure 4.9.

A large part of the residual variance is due to measuring errors: three stations even show runoff coefficients between 80% and 95%. Such values are definitely unrealistic

for areas with a mean annual rainfall of less than 2,000 mm and a potential evapotranspiration of more than 1,000 mm/year. Therefore, the real relationship could be even better than appears from the graphs, and in some cases estimates based on the regression formula should be preferred.

Table 4.8 Streamflow related to Drainage Area and Precipitation

Qmean =	$12.59*10^{-3}$	*	Area0.85	*	Rain2.7
Q80% =	$3.27*10^{-3}$	*	Area0.85	*	Rain2.7
Q96% =	$1.72*10^{-3}$	*	Area0.85	*	Rain2.7

Note: Rain = Mean annual rainfall in metres
Area = Catchment Area in Square km

These equations have been derived using all available data from perennial streams in Baringo, Laikipia, Meru and Isiolo District. In all catchments, the subsoil is predominantly volcanic and the rains are concentrated in two distinct rainy seasons. Mean annual rainfall varies between 550 and 1900 mm and the drainage areas vary between 26 and 15,300 km². The equations are probably valid throughout Kenya, and should sometimes be preferred to measured data, where rivers are perennial, the subsoil volcanic and the rains concentrated into two distinct rainy seasons.

The equations in Table 4.8 imply that the 80% and 96% flows can be estimated from the mean flow using the following proportionality:

Qmean : Q80% : Q96% = 1 : 0.259 : 0.136

4.8 Baseflow

Drought flow analysis has been carried out on the records of 14 hydrometric stations on perennial rivers draining volcanic catchments. From every ten-years period for which reliable records are available, one or two of the severest droughts were analysed. Master recession curves were constructed by combining individual recessions on a semi-log scale (Appendix 4.7). Equations were fitted to the data points. In some cases where the scatter is high the regression line is drawn through the upper points as it is believed that a large part of the scatter is due to abstractions of river water. The median daily flow was taken as the typical discharge at the beginning of the dry season. The results are summarized in Table 4.9.

The only sources of drought flow are groundwater and soil moisture. In normal years, dry seasons last approximately three months. Therefore, baseflow after 90 days an be considered as typical discharge of groundwater from the aquifers which are subsequently recharged when the next rainy season sets in.

There are two rainy seasons and two dry seasons, each lasting about three months. Groundwater continues to emerge during rainy seasons resulting in a higher rate of baseflow. In these rainy periods, baseflow is at least 50% higher as aquifers are continuously recharged. In this way the mean annual baseflow is estimated to amount

to at least five times the baseflow during a typical dry season of 3 month. This amount roughly equals the annual recharge.

Thus, a conservative estimate of the recharge can be made by multiplying the baseflow volumes after 90 days (Table 4.9) by a factor 5. This yields a annual recharge of 335 mm in 4E, 220 mm in 4F, and 140 mm in 5BE. Thus, the mean annual recharge amounts to 230 mm.

These data are valid for the source areas of the rivers, so the whole of Meru District minus the Basement Area and the semi-arid Volcanic Plains. In total an area of 4809 km² with an average annual rainfall of about 1300 mm. Therefore it can be concluded that the average baseflow and recharge equals at least 20% of the annual rainfall.

The severest drought on record, that of 83/84 lasted about nine months. During and after the following rainy season, baseflow levels remained lower than normal. Thus more groundwater was depleted during the 83/84 drought than could be replenished during the following rainy season.

The mean baseflow volumes after 90 days differ strongly between the subcatchments: 67 mm for 4E, 44 mm for 4F and 28 mm for 5BE. The high values for drainage area 4 and the lower values for drainage area 5 can be explained by the humid to semi-humid windward environment of the catchments in drainage area 4 and the dryer conditions in drainage area 5 on the leeward side. However the difference between 4E and 4F is puzzling: the 4F basins receive more rainfall while there is no reason to assume that transmissibilities are higher in drainage area 4E than those in 4F.

Table 4.9 Estimates of Aquifer Depletion from Hydrograph Analysis

River	RQS	Area km²	Typical Qo cumec	Recession Constant	After:	Run - Off				
						30	60	90	180	270 days
Mutonga	4EA6	624	6.31	0.00416	Mm^3	15.4	28.9	40.9	69.07	88.43
					mm	24.6	46.4	65.6	111	142
Nithi	4EB1	120	1.99	0.00685	Mm^3	4.66	8.46	11.6	17.79	21.15
					mm	38.9	70.5	96.3	148	176
Tuchi	4EB4	111	2	0.008364	Mm^3	4.58	8.15	10.9	16.08	18.5
					mm	41.3	73.4	98.4	145	167
Ruguti	4EB6a	368	2.5	0.006571	Mm^3	5.9	10.8	14.7	22.89	27.4
					mm	16	29.2	40	62	74
Tunga	4EB9	80	0.63	0.012778	Mm^3	1.36	2.28	2.91	3.833	4.125
					mm	17	28.5	36.4	48	52
Thingithu	4F4	303	1.9	0.00511	Mm^3	4.57	8.48	11.8	19.32	24.04
					mm	15.1	28	39.1	64	79
Thangatha	4F8	210	2	0.0105	Mm^3	4.45	7.69	10.1	13.97	15.49
					mm	21.2	36.6	47.9	67	74
Ura	4F9	198	2	0.013143	Mm^3	4.28	7.17	9.12	11.91	12.77
					mm	21.6	36.2	46.1	60	64
Kathita	4F10	878	6.92	0.005476	Mm^3	16.5	30.6	42.5	68	84.29
					mm	18.8	34.8	48.4	78	96
Thingithu	4F17	303	1.9	0.0050	Mm^3	4.57	8.51	11.9	19.48	24.32
					mm	15.1	28.1	39.3	64	80
Ontulili	5BE2	64	0.32	0.0209	Mm^3	0.62	0.95	1.12	1.292	1.318
					mm	9.63	14.8	17.5	20	21
Teleswani	5BE5	36	0.25	0.00192	Mm^3	0.63	1.22	1.79	3.287	4.551
					mm	17.5	34	49.6	91	126
Liki	5BE7	176	1	0.0265	Mm^3	1.79	2.6	2.96	3.233	3.258
					mm	10.2	14.7	16.8	18	19
Ewaso Ngiro	5E3	15300	10	0.023711	Mm^3	18.5	27.7	32.1	35.93	36.38
					mm	1.21	1.81	2.1	2	2
Mean	4E				mm	28	50	67	103	122
Mean	4F				mm	18	33	44	67	79
Mean	5B				mm	12	21	28	43	55
Overall Mean					mm	19	35	46	71	85

4.9 Surface Water Quality

Analyses are available of 180 samples taken from rivers and streams in Meru during the period 1985 - 1988 (Appendix 4.7). The samples were taken from 105 different locations along 49 different streams. Only samples of which the locations were evident were selected.

The accuracy of many of the analyses is not high. A difference in the ionic balance of the major cations and anions of 5% is generally considered acceptable, but this is only the case for 24 samples. Even when this difference is relaxed to 10% only 43 can be considered acceptable. However, most analyses are still usefull as they indicate orders of magnitude of the concentrations.

The water quality of streamflow in the Mount Kenya area and the Nyambeni Hills is generally very similar. It is characterized by a low mineralization resulting in a low electrical conductivity (mean: 122 μS, st. dev: 97), and thus a low amount of dissolved solids (mean TDS: 74 mg/l, st. dev: 58). It is also very soft (mean: 29.3 mg/l, st.dev: 23.8). The maximum value of 936 μS or 562 mg/l at Nkubu looks like an instrument error. The highest mineralized water can be found in the Basement Area at Mulika and Murera with TDS values of more than 200 mg/l.

The rivers carry more sediments during the rainy seasons (March-May and November - December). This raises the concentrations of some of the elements (iron, manganese) while lowering the concentrations of the major cations and anions.

The average pH-value is 6.8 with a standard deviation of 0.8. The minimum value is 3.0, while the highest value is 8.9. This minimum value is probably due to a faulty pH meter. A pH-value of less than 6.5 is found in about 38% of the samples. This is a very high proportion for natural water and is possibly due to faulty meters and/or a long waiting time between sampling and analysis. Water with a pH of less than 6.5 is considered unsuitable for human consumption.

The pollution of water with organic matter is very low. It exceeds in only about 3% the norm of 20 for the KMn04 value while nitrate and amonia levels are also very low. This is an indication that most samples were taken under fair weather conditions when suspended sediment concentrations and associated turbidity, iron, manganese and organic matter concentrations are low.

Appendix 5.5 lists a number of norms which render water unsuitable for domestic use if exceeded. Applying these norms on the available analyses, only 62 samples (31%) are chemically suitable for domestic use. However this figure of 31% is mainly due to a pH-value of less than 6.5 and given the doubts about the reliability of the measurements probably too pessimistic.

Filtration and simple chemical treatment will make most surface water above the Chuka - Meru - Nanyuki Road suitable for domestic use. Below this line, more complicated treatment is probably necessary as most towns lie on this road.

A growing problem, however, is the seasonal pollution from coffee factories after the rainy seasons, in June-July and November-December. As discharge of coffee waste water usually takes place during the night, the magnitude of the problem is difficult to assess.

Surface water in Meru is suitable for all types of irrigation as evidenced by the low values of the Sodium Absorption Ratios (SAR).

Surface water in Meru is suitable for all types of irrigation as evidenced by the low values of the Sodium Absorption Ratios (SAR).

5. HYDROGEOLOGY

5.1 Introduction

Chapter 5 on hydrogeology gives a brief description of the aquifer systems identified in the District.

Based on previous geological studies two different types of aquifer systems can be distinguished, viz: the interconnected regional aquifer systems of the volcanic areas and the isolated local aquifer systems of the Basement region.

Geophysical investigations were undertaken to determine the thickness of the volcanic covers overlying the Basement (chapter 3). The hydraulic properties of the aquifers were then further investigated by testhole drilling and subsequent testpumping, especially in areas where data were sparse.

Groundwater flowing in these aquifers discharges through springs and as seepage in streams. Inventories of springs and wells, and baseflow studies were therefore undertaken to analyse the behaviour of the various groundwater systems and the chemical quality of the water originating from them.

Details on data collected can be found in the volume 'Appendices' of the Water Resources Assessment Study.

5.2 Previous Hydrogeological Studies

Only three hydrogeological studies of parts of Meru District could be traced. These studies cover only limited areas and are of a general nature. Their results are briefly outlined below.

(a) Tigania Water Supply - Hydrogeological Study Report (Cowiconsult, 1980):

There were no boreholes within the study area, so analysis of aquifer characteristics was based on boreholes outside the project area, notably those around Isiolo whose tested yield vary between 4.5 m^3/hr and 16 m^3/hr. The boreholes were drilled in the Lower Nyambeni lavas. Aquiferous properties of volcanic rocks vary strongly: unfractured solid basalt is almost impervious while fractured and porous lava or basalt with contraction joints can be very pervious (up to an hydraulic conductivity of 1,000 m/day). In some cases, weathering processes may increase the aquiferous properties of the formation.

Aquifers are also found in old landsurfaces, such as between the Upper and Lower Nyambeni Lavas, between Nyambeni lavas and lavas from vents and craters, and finally between Nyambeni lavas and the Basement formation.

A number of springs found in Tigania have also been listed in this report, together with their respective discharges.

(b) An investigation into the Water Resources of the Ewaso Ngiro Basin, (Ministry of Works, 1963):

The volcanic rocks which cover the greater part of the upper catchment of Mount Kenya area are highly impermeable but due to the presence of comparatively thin old land surface deposits between lava flows, there are important aquifers beneath most of the area. The groundwater contained in most of these aquifers, is essentially confined. There are springs fed from high level aquifers especially to the west of Marania river where there is a spring line at about 2,400 metres. At lower levels, near the 1,800 metres contour, there is another area of seepage. So the spring water seeps through porous or fractured formations at a certain level only to come out as a spring at a much lower level.

On the flanks of the Nyambeni Hills, water is likely to be struck at uneconomic depths and for this reason drilling sites at or above the 1,500 metres contour have to be selected with caution.

In the Basement area, it is not recommended to look for borehole sites near Inselbergs as the Basement rock below tends to be impermeable.

(c) The Sweet Water of Meru District (Tole and M'Ragwa, 1987):

There are several cold water springs with pleasant-tasting water in Meru District. The springs range from gas-poor water springs to water-poor gas springs. The pleasant tasting springs have high carbon dioxide ($C0_2$) content and their chemical composition is similar to that of natural mineral water, currently imported from Europe.

The springs occur to the east of Mount Kenya at altitudes ranging between 1,500 and 2,700 metres. Geologically the springs occur within areas underlain by phonolites, kenytes, trachytes, basalts, rhombi-porphyries and pyroclastics of Mount Kenya suite of Pleistocene age.

5.3 Data Collected and Analysed by WRAP

5.3.1 Landsat Data and Aerial Photographs

The district is covered with MSS colour composites for bands 4,5 and 7. One scene covers the whole district and was printed by Regional Remote Sensing facility in Nairobi at a scale of 1:250,000. The Landsat image was mainly used in delineating the geological units that determin the groundwater zones and in delineating the forest (Section 5.4 and Plate 5.1).

Aerial photographs were used in site evaluation for boreholes in Lare-Mutuati area.

5.3.2 Springs

Meru district is one of the districts in the country, that have the highest number of springs. They are especially found on the slopes of Mount Kenya and along the Nyambeni hills where both rainfall and humidity are high. In 1988 WRAP III carried out a spring inventory survey and about 550 springs were identified, 390 around Mount Kenya region and the rest in the Nyambeni Range area.

In the Mount Kenya region, the springs are mainly found in the windward eastern slope where rainfall is between 1400 mm and 1800 mm. On the leeward northern slope of the mountain the rainfall is much less ranging between 600 mm and 800 mm and springs are fewer. On the eastern slope gauging of the springs was mainly done in the agricultural area below the forest. The springs are few at the lower parts of the slope and only rarely were springs found below 1200 metres. For the area between Thuchi and Igoji, the majority of springs are found between 1200 metres and 1700 metres while the area north of Igoji springs are concentrated at a much higher altitude. Between Kazita and Marania rivers, there are virtually no springs and the area seems to act as a water divide with Kazita draining to the Tana River basin and Marania to the Ewaso Ngiro River basin. West of the Marania River several springs are found along 2,600 metres contour.

The number of the springs increases in a downward direction which can be explained by a decreasing total thickness of the aquifers and by a decreasing permeability because of finer material.

In the lower eastern slopes of Nyambeni hills in and around the Meru National Park there are a number of big springs. Some of the major springs emerge at about 1000 along the western perimeter of the park. This area defines a discharge zone for groundwater recharged in higher areas of the Nyambeni hills. The Basement system forms a groundwater barrier in this area since it is near the surface. There are several springs at altitude from 1300 to 1400 metres and 1700 to 1800 metres defining the aquifer levels in the Nyambeni Ranges. Some other were dry, especially in Lare area in Ntonyiri Division where problems of acute water shortage occur.

Appendix 5.1 lists the springs included in the inventory.

5.3.3 Boreholes

Inventory of Boreholes

During the borehole inventory carried out by WRAP III in the months of November and December 1987, a total of 103 boreholes were visited. These included the newly drilled boreholes (about 25 in number) by SIDA in Tharaka Division (1986-87) and more than 70 boreholes by Plan International in Igembe and Ntonyiri Divisions (1986-88). They can be categorised into six groups (Figure 5.1).

As has been mentioned earlier, most boreholes were drilled between 1986 and present, mainly in Tharaka and Igembe Divisions and to a lesser extent in the newly created Ntonyiri Division. The rest, about 20 boreholes, are scattered mostly on the slopes of Mount Kenya along the Chuka - Meru - Timau axis.

Boreholes Drilled by WRAP

The WRAP III drilling rig has in the period 1989-90 drilled 19 boreholes out of which 13 yielded water. They are distributed over the District but majority (five) are in the Northern Grazing Area. Three are located in Kirwa, Kibirichia and Ruiri area, one at Birikine and another at the Migutuini health centre. The criteria used to site these boreholes were mainly to provide more data on the aquifer characteristics in these areas. But the boreholes also supplemented the water demand in their respective localities except C7923, C7928 and C8327 in Kirwa and Kibirichia in which no water

Table 5.1 Boreholes Drilled by WRAP

BH NO	LOCATION	Coordinates		Sheet No	Surface Elevation (m)	Total Depth (m)	Water Struck level		Water Rest Level		Tested Yield m^3/h (airlift)
		X	Y				Depth (m)	Elevation m + msl	Depth (m)	Elevation m + msl	
C7923	Kiirua Dispensary	0 07'22"N	37 33'08"E	108/3	2004	136	76	1928			Dry
C7924	Isiolo Air Strip	0 20'18"N	37 35'49"E	108/1	1040	184	32,58, 112	928	18	1022	>15
C7925	Ngare Mara River	0 23'35"N	37 40'06"E	108/1	1025	48	26	999	19	1006	>30
C7926	Near Bule Shime River	0 25'57"N	37 45'55"E	108/2	1057	138	52,78, 94	1005	41	1016	45
C7927	Near 78 Barracks	0 21'42"N	37 36'39"E	108/1	1080	78	22	1058	15	1065	>15
C7928	Kiirua Mission	0 07'50"N	37 33'58"E	108/3	1951	200	-	-	-	-	Dry
C8327	Kibirichia	0 06'15"N	37 30'29"E	108/3	2332	239	-	-	-	-	Dry
C8974	Ruiri Coffee Factory	0 09'19"N	37 39'12"E	108/3	1501	102	87	1414	33	1468	18
C8975	Magutuni Dispensary	0 13'17"S	37 44'08"E	122/1	1200	180	12,30	1170	9	1191	3.0
C8976	Ngare Mara Village	0 29'34"N	37 38'20"E	108/1	950	46	31	919	21	929	>30.0
C8977	Mbirikine School	0 01'13"N	37 50'13"E	108/4	1013	72	6.5	1006	6.5	1007	18
C8978	Tutua	0 11'58"N	37 35'47"E	108/3	1600	90	71	1529	56	1544	12
C9081	Kianjai	0 10'08"N	37 45'16"E	108/4	1402	60	8,42	1360	7	1395	30
C9082	Liliaba	0 19'00"N	37 50'18"E	108/2	1341	95	82	1259	65	1276	24
C9083	Near Ndoleli Primary School	0 18'56"N	38 03'37"E	109/1	965	9	70,82	830	59	906	24
C9084	Malaeni	0 19'12"N	38 05'03"E	109/1	900	120	70,72, 114	808	56	844	36
C9085	Meru (Ask) Show Ground	0 04'14"N	37 37'45"E	108/3	1704	120	39,94	1665	70	1634	70
C9282	Meia Crater	0 21'51"N	37 52'53"E	108/2	1402	42	Abandoned due to caving			-	Dry
C9283	Mburieni	0 24'27"N	37 53'29"E	108/2	1326	84	Abandoned due to caving			-	Dry

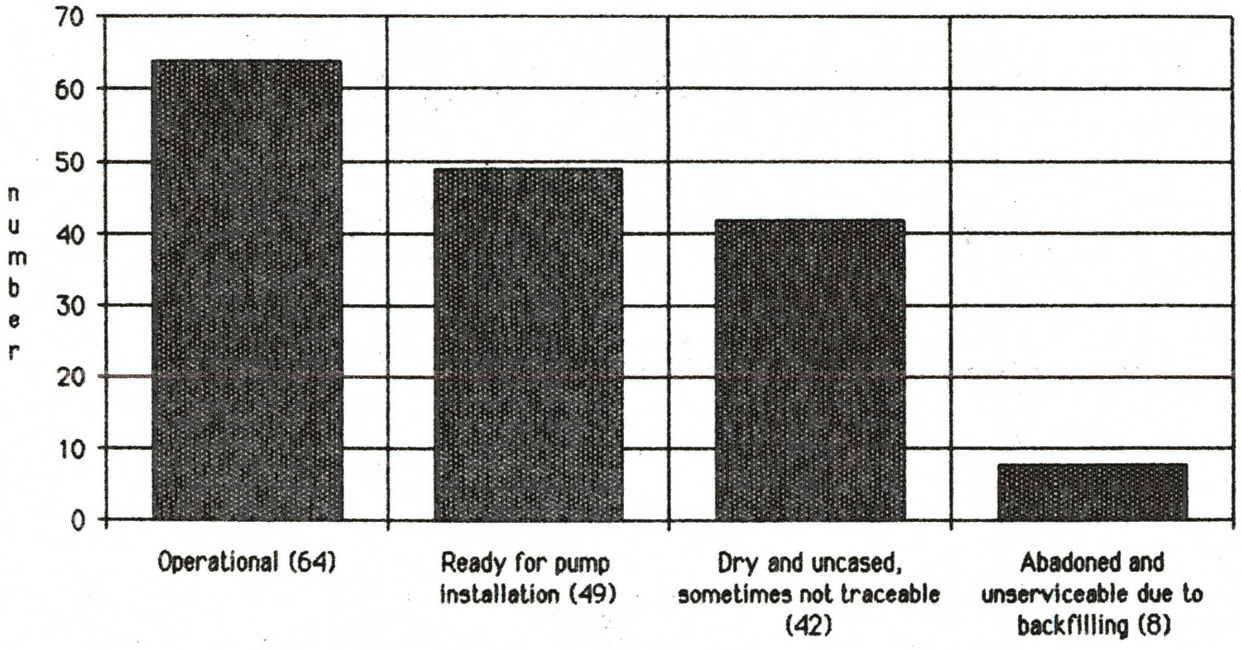


Figure 5.1 Condition of Boreholes in Meru District

was struck. Table 5.2 shows the characteristics of the boreholes i.e total depth, water struck level, water rest level, yield etc.

Appendix 5.1 lists the available data for all the boreholes in the district and Plate 5.1 shows the location of them.

5.3.4 Groundwater Levels

Continued groundwater level monitoring was undertaken for 18 boreholes selected in February 1988. Six are in Tharaka, the rest are distributed in the remaining area ofthe District. The exercise was carried out on a quarterly basis. The readings can be seen in Table 5.3.

5.3.5 Pumptests

Data from more than 20 pumping tests are available in the archives of the Ministry of Water Development. Quantitative interpretation is difficult because pumping rates are unstable, decreasing to about 30% of their initial rate. Therefore no attempt was made to analyse these tests.

In recent years pumptests have been carried out by WRAP III (see appendix 5.3). Five boreholes that have been tested, are in the Northern Grazing Area, one in Ruiri and two in Tharaka Basement area. All but the last two were drilled by WRAP III Borehole C7925 and C7926 has the highest transmissivity values of both 811 m^2/day and borehole C7924 has the lowest value of 3.3 m^2/day. Table 5.2 shows respective transmissivities of boreholes for both pumping and recovery phases.

Table 5.2 Summary of Groundwater Sub-zones

SUBZONE	AREA	LITHOLOGY	AQUIFERS	SPRINGS				BOREHOLES						General water quality
				No	Discharge (80% prob.level) mean maximum l/sec	total l/sec	specific l/sec/km2	No	Success rate	Discharge mean maximum m3/h	Struck levels mean range m	Rest levels mean range m	Borehole depths mean range m	
	km2													
Mt Kenya: Upper and Middle Slopes	1246	Phonolites, trachytes, Kenyte lavas, agglomerates	regional: cinderlayers old land surfaces	many	high	high	high	no boreholes						very good
Mt Kenya: Windward Lower Slopes	987	Phonolites, Kenyte lavas tuffs, agglomerates	regional: cinderlayers old land surfaces	307	7.4 113	2263	2.29	11	100%	9.6 70	53 12-170	53 8.5-150	129 21-201	very good
Mt Kenya: Leeward Lower Slopes	651	Trachytes, tuffs agglomerates	regional: cinderlayers old land surfaces	24	5.6	134	0.21	12	82%	4.6 13.7	76 34-157	60 16-151	93 50-157	very good
Mt Kenya Deep Aquifer Zone	200	Coarse pyroclasts	very good extensive aquifers at greater depth	6	0.19	1.2	0.01	4	25%	0.13	82	no rest level	190 136-239	no data, but probably good
Mt Kenya: Compact Tuff Area	137	Compact tuffs	very poor aquifers	0	0	0	0.00	no boreholes, but successrate and yield are expected to be very low						no data
Nyambeni Hills	457	Phonolites, tephrites	regional: cinderlayers old land surfaces	125	11.3	1408	3.08	13	69%	5.1 10.3	40 4.5-116	30 1.6-101	55 18-120	very good
Nyambeni Deep Aquifer Zone	394	Coarse pyroclasts, basaltic lavas, phonolites, tuffs	very good extensive aquifers at greater depth	2	5	10	0.03	13	15%	2.7	45 28-76	61 39-84	78 49-104	no data, but probably good
Volcanic Plains	2565	Basalts, pyroclasts	regional: pyroclasts, old land surfaces	45	9.4 45	421	0.16	75	85%	10.5 100	40 5-115	30 0-100	66 11-213	good
Basement Area	2546	Metamorphic rocks, alluvium colluvium	local: weathered zones, faults,fractures,alluvium	0	0	0	0.00	33	55%	3.1 10	13.8 2.0-40	6.1 1.5-24	29.1 9.0-57	Poor to fair: overall success rate is only 30%

5.3.6 Chemical Data

By the end of the project, 142 chemical analyses of water samples from boreholes, 23 from water supplies, 30 from springs and 15 from wells were available in the archives of the MoWD. These number include the samples taken within the framework of the project.

Unfortunately, the accuracy of the analyses is not high. A difference of a ionic balance of the major cations and anions of 5% is considered acceptable, but this is only the case for 44 samples (21%). Even when this difference is relaxed to 10% only 87 samples (41%) can be considered acceptable. However, most analyses are still usefull as they indicate orders of magnitude of the concentrations.

5.4 Groundwater Zones

In Meru District four main groundwater zones have been identified. These are:

- Zone I - Mount Kenya
- Zone II - Nyambeni Range
- Zone III - Volcanic Plains
- Zone IV - The Basement Area

Based on the available data on geology, springs and boreholes, the interpretation of Landsat images and the analysis of previous studies, these four main zones have been further subdivided into sub-zones. These sub-zones are shown on Figure 5.2 and in the hydrogeological map (plate 5.1) while their hydrogeological properties have been listed in Table 5.2.

These zones can be grouped into two different aquifer systems, viz regional and local systems. The fissured and/or weathered volcanic rocks (Zones I, II, and III) often interbedded with old land surface deposits can be considered *regional aquifer systems* with interconnected groundwater flow. The fissured and or weathered Basement System rocks (Zone IV) comprise many *isolated local aquifer systems* without interconnections.

5.4.1 Mount Kenya - Zone I

All available data indicates that Mt Kenya can be considered as one major hydrogeological system. Conditions above and below the ground surface, however, vary strongly with rock-type, elevation and exposure. In order to take this into account, the Mount Kenya area of 3221 km² is sub-divided into five zones:

- Zone IA - the un-surveyed Middle and Upper Slopes
- Zone IB - the Windward Lower Slopes (the Meru-Chuka area)
- Zone IC - the Leeward Lower Slopes (the Timau area)
- Zone ID - the Deep Aquifer Zone (the Kirua-Kibericha area)
- Zone IE - the Compact Tuff area

The chemical quality of groundwater in Mount Kenya is generally satisfactory.

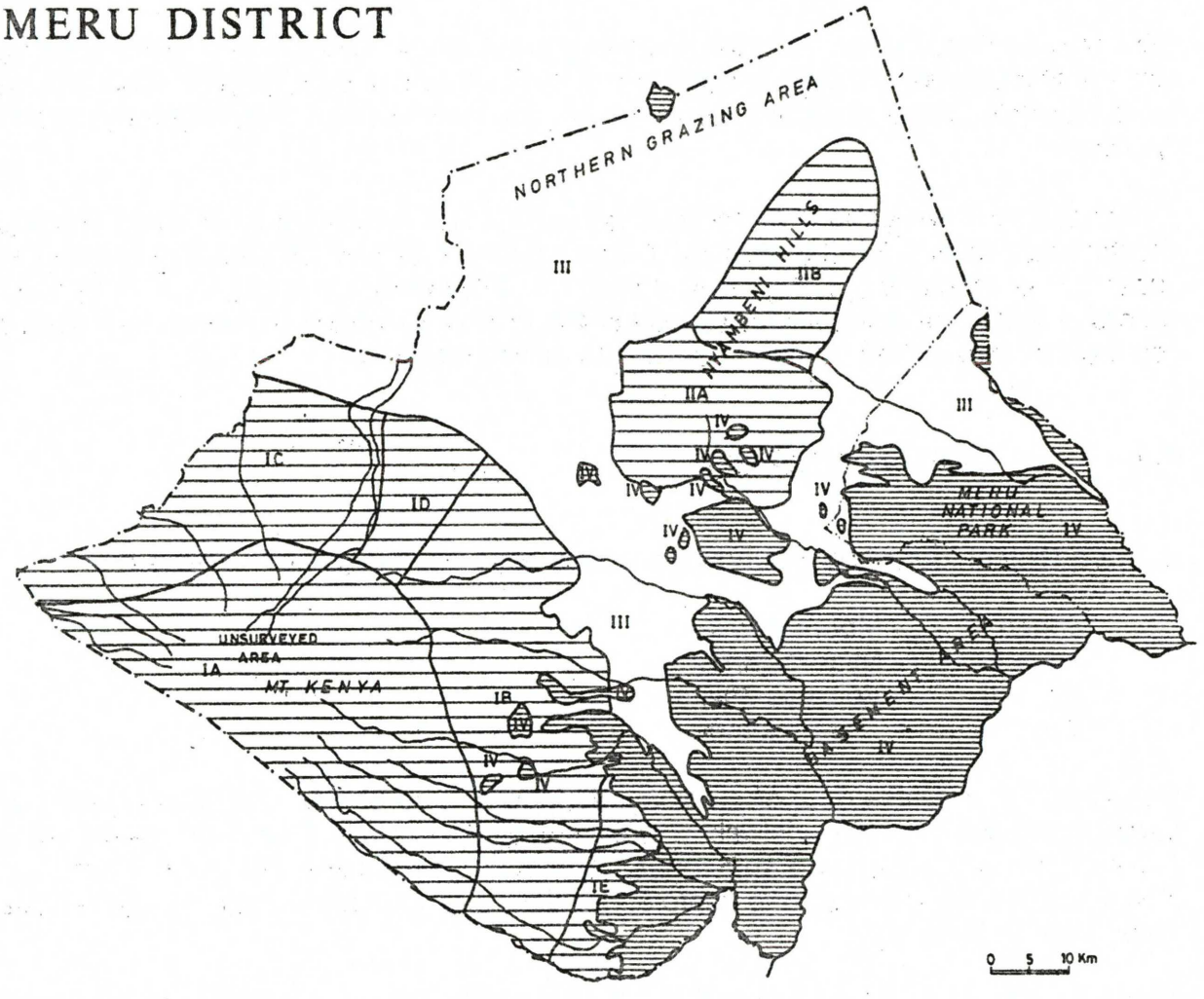


Figure 5.2 Hydrogeological Zones

The Upper and Middle Slopes of Mount Kenya (Zone IA)

This area was not surveyed because of its inaccessibility. There are many springs but no boreholes. The water quality is good to very good.

The *Upper Slopes of Mount Kenya* being the zone situated at above approximately 4000 meters consists of predominantly steep terrain with moorlands and ice regions. Several glaciers drain to the Ewaso Ngiro and Tana catchments although streamflow from this area is relatively small.

The climate is semi-humid with annual rainfall of less than 900 mm and annual potential evapotranspiration of less than 1400m. Due to the freezing temperatures found here, infiltration and subsequent recharge of the aquifers is very limited as a result of frozen ground.

As there are no boreholes in this area, the following description of the hydrogeology is mainly based on surface observations on Mount Kenya. The main feature in this area is the central syenite boss covered with steep radial valleys which joins the gentle sloping area where moorlands tend to develop in flat and poorly drained areas. Moorlands are also found where impervious layers occur near the surface.

The rocks in this zone consists of phonolites, Kenyte lavas, tuffs and agglomerates. Lava flows tend to thin out with increasing distance from the central boss of syenyte. They are usually rather impervious but the old landsurfaces in between can be very permeable if not sealed by permafrost.

The *Middle Slopes of Mount Kenya*, situated between the 2400 and 4000 m contour-lines, co-incide roughly with the zone of maximum rainfall. As a result, the climate is humid with annual rainfall exceeding locally 2,000 mm. The area is covered with rainforest which tends to thin out to the leeward north-western side of the mountain where little true forest is left.

The rocks of this zone consist of trachytes, agglomerates, basalts in the central and northern parts of the area and phonolitic kenyte lavas in the southern parts. The aquifers are the same as described under the Upper Volcanic Slopes, but with an important difference: the transmissibility is lower as it decreases in a downstream direction. This is because, with increasing distance from the summit, (i) the total thickness of the waterbearing volcanics decreases and (ii) the cinders and ashes become gradually finer, and consequently their permeability lower.

Springs tend to occur in very high numbers in the lower parts of the windward side of the mountain which coincides roughly with the rainfall maximum. Recharge in this area is very high as a result of the high rainfall, the generally high infiltration capacity of the forest soils and the deep groundwater table at the divides.

The area can be characterized as an groundwater transmission and recharge area.

The Lower Slopes of Mount Kenya (Zones IB, IC, ID, IE)

This zone rises from approximately 1200 m above MSL on the eastern windward slope of Mt Kenya, and from approximately 1500 m on the northern leeward slope to approximately 2400 metres above MSL. Mean annual rainfall varies between 1200 mm and 1800 mm on the windward side and between 600 and 800 mm on the leeward

side. The potential evapotranspiration is around 1500 mm, so the windward slope has a semi-humid to humid climate while the northern leeward slope has a semi-humid to semi-arid climate.

Groundwater flow is radial and a broad reflexion of the topography. Water rest levels are generally at around 60 metres below ground surface (Table 5.2).

The *Windward Lower Slopes (Zone IB)*, roughly the area between Chuka and Meru, covers an area of 2565 km². Its upper limit coincides with the forest.

The subsoil comprises phonolitic Kenyte lavas, tuff and agglomerates.

Numerous springs emerge in this area: 307 springs were identified during the spring inventory. The average 80% discharge was 7.4 l/sec with a maximum of 113 l/sec yielding an specific spring discharge of 2.29 l/sec/km² (equal to 72 mm/year).

There are only 11 boreholes in this area, or 1 per 240 km². Several boreholes are situated near springs raising the question whether cheaper and more reliable alternative water sources were considered. All boreholes were successful although in one case drilling had to go beyond 170 m. Their mean discharge amounts to 9.6 m3/h with a maximum of 70 m3/h. Water struck levels are at 53 m with a maximum of 170 m.

The quality of groundwater, both from springs and boreholes is excellent.

In conclusion this is an area with abundant water resources, both in streams and under ground. In most cases springs can offer cheap and very reliable water sources. Only where springs are absent, alternatives like boreholes or streams should be considered as water sources.

The northern *Leeward Lower Slopes (Zone IC)*, roughly the area between Nanyuki and the Marania river, covering 651 km². Its upper limit coincides roughly with the forest.

The subsoil comprises of trachytes, tuffs and agglomerates.

Mean annual rainfall does not exceed 1000 mm. Therefore, infiltration and recharge are less than on the windward side resulting is considerable fewer springs. Only 24 springs could be identified in this area yielding a spring density of 1 per 27 km². The average 80% discharge was 5.6 l/sec yielding an specific spring discharge of only 0.21 l/sec/km² (equal to 7 mm/year).

Only 12 boreholes were found in this area, or 1 per 54 km2. Eleven boreholes (83%) were successful although in one case drilling had to go beyond 156 m. The mean discharge amounts to 4.6 m³/h with a maximum of 13.7 m³/h. Water struck levels are at 76 m with a maximum of 157 m. Water rest levels found at 60 m with a maximum of 151 m.

The quality of groundwater, both from springs and boreholes is excellent.

In between these two sub-zones, *the Pyroclastic Deep Aquifer Zone (Zone ID)* covers an area of about 200 km². The area is dotted by fresh parasitic cones consisting predominantly of coarse pyroclastics. Exploratory drilling was very difficult because of these extremely pervious rocks which could not contain the drilling mud. Only very few massive lava layers were encountered. The borehole at Kibericha was discontinued at

240 metres without striking any significant amounts of groundwater.

The geology of this area is very similar to that of the eastern part of the Nyambeni Range which is also dotted with fresh parasitic cones.

Mean annual rainfall varies between 750 and 1000 mm. A large part of it infiltrates, and percolates through the coarse pyroclastics to great depth. Due to the extreme high vertical permeability of the rocks, there are no developed surface drainage pattern The flows of the springs identified during the spring inventory are so low that it is concluded that those springs emerge from small, isolated perched aquifers. They are probably non-permanent.

Nevertheless, it is likely that there are very productive aquifers at greater depth, possibly as productive as those underlying the Northern Grazing Area. Water quality is probably very good.

There is only one small area of 137 km² without groundwater development potential, and that is the *Compact Tuff Area (Zone IE)*, situated below Chuka and Chogoria. The boundaries with the adjacent sub-zone, the windward Lower Slopes are only tentative. The subsoil consists of very fine, compact tuffs of the Kenyte lava series. Deformations, cracks, fractures or faults are virtually absent.

The climate is sub-humid: the mean annual rainfall is around 1400 mm while the annual potential evapotranspiration varies between 1800 and 2000 mm.

There are no springs in this area, and no boreholes.

In order to get some information from this area, an exploration borehole (C8975) was drilled by the Project at Magutuni Dispensary. There was only some water in the weathered upper part, between 12 and 30 m. But up to 180 m it was all compact tuff. A pumptest conducted with the pump at the lowest pumping rate emptied the borehole in a few minutes.

5.4.2 Nyambeni Range - Zone II

All available data indicates that the Nyambeni Uplands can be considered as one major hydrogeological system. The boundary with the Volcanic lowlands falls between the 1100 m and 1300 contour lines. Conditions above and below the ground surface, however, vary strongly with rock-type, elevation and exposure. In order to take this into account, the Nyambeni Uplands of 1381 km² is sub-divided into two strongly contrasting zones:

- Zone IIA - the Nyambeni Hills
- Zone IIB - the Deep Aquifer Zone (the Lare area)

The chemical quality of groundwater in the Nyambeni Range is generally good to very good.

The Nyambeni Hills (Zone IIA)

This sub-zone of 987 km² constitutes the Nyambeni Hills proper. Its highest point reaches 2400 m. It is one of the rainiest parts of the country: the annual rains vary between 1400 to 2400 mm. The annual potential evapotranspiration varies between 1600 to 1800 mm giving a predominantly humid climate.

The subsoil consists of mainly phonolites and tephrites. They are often massive lava flows and very suited to form perched aquifers.

The rainy windward side of the area is dotted by numerous springs whereas there are only few on the leeward side. A total of 125 springs were identified during the spring inventory yielding a spring density of 1 per 7.9 km2. The mean discharge amounts to 11.3 l/sec, the highest in Meru District. The specific spring discharge amounts to 3.1 l/sec/km² (equal to 98 mm/year).

There are 13 boreholes in this area, most of them drilled by Plan International giving a borehole density of only 1 per 76 km². The success rate of only 69% can be explained by the fact that this organisation did not drill beyond 70 metres as the boreholes were meant to be equiped by handpumps. The mean discharge is 5.1 m³/hour. The average water struck level is at 40 m (maximum 116 m) and the rest level at 30 m (maximum 101 m).

Interestingly, the spring density in this area is virtually the same as the spring density of the windward Lower Slopes of Mount Kenya, although the average flow is about 55% higher in the Nyambenis.

It is obvious that the infiltration and consequent recharge are very high, exceeding the vertical flow capacity. As a result, many perched aquifers are overflowing which give rise to numerous springs.

The water quality is excellent.

The Deep Aquifer Zone (Zone IIB)

This zone lies between the 1000 m contours near the eastern corner of the District and 1800 m elevation around Lare.

The mean annual rainfall of 2000 mm around Lare decreases rapidly to 400 mm around Kulamawe. The potential evapotranspiration ranges between 1600 mm around Lare to more than 2200 mm around Kulamawe.

The area is characterized by a series of parasitic volcanos and vents running in a north-eastern direction. The subsoil consists of basaltic lavas, phonolites, tuffs and coarse pyroclastics. The geology of the area is very similar to that of the Kibericha Kirua area at Mount Kenya which is also dotted with fresh parasitic cones.

Despite the high rainfall, a surface drainage system in this area is not developed. This points to a very high infiltration capacity. There are only very few springs, mostly stagnant pools without significant outflow. They occur in areas where compact thin lenses of basalt are found within pyroclasts.

A large part of the rain infiltrates, and percolates through the coarse pyroclastics to great depth, facilitated by the extreme high vertical permeability. From here, it travels in a horizontal direction to the Ewaso Ngiro and to a line of major springs at the boundary of the Meru National Park. The total flow of this line of springs exceeds 1 m3/sec!. This points to the existence of very productive aquifers at greater depth, possibly as productive as those underlying the Northern Grazing Area.

There are 13 boreholes in this area. Eleven were discontinued without striking any significant amount of groundwater. Only two were successful with an average yield of 2.7 m^3/hour. This is another clear indication that rain water percolates rapidly to greater depths.

Water quality of this deep aquifer is probably very good.

5.4.3 Volcanic Plains - Zone III

This zone covers most of the northern side of the district, and some parts in the central area, and the southern and eastern slopes of the Nyambeni Hills. The plains are at elevations between 600 and 1500 metres above sea level. Annual rainfall varies from 450 mm at Kinna and 650 mm at Isiolo to about 1000 mm. As a result, recharge from precipitation is low. Groundwater comes from the high rainfall areas of the Nyambeni and Mount Kenya Ranges. The mean annual potential evapotranspiration in this zone varies from about 1800 mm in the saddle between Mount Kenya and the Nyambenis to over 2000 mm in the Northern Grazing Area and Meru National Park.

The rocks in these areas consists of mainly basalts (Lower Nyambeni Basalts) although in some cases volcanic ashes are found in pockets with recent volcanic activity. These lavas extend downwards from the flanks of the Nyambenis and Mount Kenya onto the peneplain formed across the gneisses and schists of the Basement System in the Northern Grazing Area and to the east in the Meru National Park. Thicknesses of the basalts are relatively small, compared to the other volcanic zones. They may vary from almost zero to 300 m.

The aquifers in this zone are predominantly regional. Along the Isiolo-Garbatulla Road in the *Northern Grazing Area*, the Project drilled four boreholes. All boreholes were successful, and three out of four high yielding to very high yielding. In borehole C7926, drilled in coarse pyroclastics, pumping at full capacity (10.8 m^3/hour) brought about a drawdown of only 6 cm. This points to a transmissibility in the range of 3000 to 4000 m^2/day. Together with the absence of permanent rivers in the area and the occurrence of major springs along the Ewaso Ngiro, this is clear evidence that the Northern Grazing Area is underlain by very good regional aquifers through which recharge from the Nyambeni Range flows underground to the Ewaso Ngiro. So, the zone between the Nyambeni Range and the Ewaso Ngiro can be characterized as groundwater transmission area. The best aquifers are found in medium to coarse pyroclastics but also cinderlayers between lava flows can make good aquifers.

The water quality of the four boreholes is good except in C7924 near the Isiolo airstrip which had water with an E.C. between 3500 and 5600 μS/cm. Nevertheless, it is quite likely that this salinity is just a contamination from the drilling process. There were a lot of problems with the drilling of this hole and a lot of chemicals and mud had to be used, clogging the hole in the process and raising the salinity of the groundwater.

Nevertheless it is likely that the chemical quality in parts of the Northern Grazing Area, especially in the north-eastern part, is not very good: electrical resistivities are low while springs along the Ewaso Ngiro are slightly saline. A possible explanation of this phenomenon is that groundwater on its way from the Nyambenis to the Ewaso Ngiro is in contact with salt containg lake deposits underneath the lavas.

The *area bordering the Meru National Park*, on the south-eastern slope of the Nyambeni is characterized by a number of huge springs which follow the perimeter fence. It is likely that the impervious Basement Rocks come near the surface forcing the groundwater to emerge as springs. The total discharge from those springs amounts to more than 1 m^3/sec. This water is very fresh. The source of this water must be the recharge in the Lare Area.

A number of boreholes were recently drilled by Plan International on the eastern lower slopes. Nearly all boreholes were successful though they are not as high yielding as those drilled on the Northern Grazing Area. They are meant to be equiped with handpumps, so optimal borehole construction is not critical which could partly explain their relatively low discharge. The boreholes in the Northern Grazing Area drilled before the Project started were also low yielding due to poor construction.

Taking into account the high spring discharge and the fact that nearly all boreholes were successful, it can be concluded that the transmissibility is very high, possibly in the same order of magnitude as the transmissibility in the Northern Grazing Area.

This part of the volcanic plains can be classified as a groundwater transmission and emergence area.

5.4.4 Basement Area - Zone IV

This zone lies in the south-eastern part of the District. It forms a low-lying undulating landscape which is occasionally interrupted by Inselbergs. Rainfall is scarse, ranging from 600 to 900 mm/year.

The zone is wholly made up of metamorphic rocks of the Basement System, consisting of meta-sediments of psammitic, pelitic and calcareous types. Regional aquifers are not found in Basement areas. Major parts are completely impermeable. Zones with aquiferous properties only develop locally, in intensively fractured or weathered areas.

Groundwater in such areas is usually stagnant, and as a result suffers from quality problems.

Of the 33 boreholes identified during the borehole inventory, only 55% were successfull in terms of enough yield. The average yield of the successful ones is only 3.1 m^3/hour with a maximum of 10 m^3/hour. The mean water struck level is only 14 m with a maximum of 40 m while the average water rest level amounts to 6.1 m with a maximum of 24 m.

Nearly all boreholes are sited near seasonal and perennial streams. This was deliberately done, reasoning that rivers tend to flow along faults or weathered zones which have aquiferous properties. An additional advantage of this policy is that waterquality in such aquifers is often better than elsewhere in the Basement area because of seasonally controlled groundwater circulation.

SIDA reports that the overall success rate of boreholes is only about 30% taking into account both discharge and water quality.

By far the best aquifers are found in the alluvial deposits along the main rivers. Experience from the investigations in Samburu District shows that water quality in such alluvial deposits is good while yields can be much higher than elsewhere in the Basement.

In order to improve borehole siting in the Basement Area of Meru Ditrict use can be made of the experience obtained in Samburu District. Table 5.3 gives an overview of the average yields obtained in different lithological units.

Table 5.3 Borehole yield and Aquifer Lithology in Samburu District

	Number	Yield (m^3/hr)
Intrusives (contact zone)	2	8.60
Alluvium/Colluvium	18	6.50
Pelitic/Semi-pelitic	17	2.52
Granitic Basement	22	1.39
Migmatitic	2	0.60

5.5 Groundwater Level Fluctuations

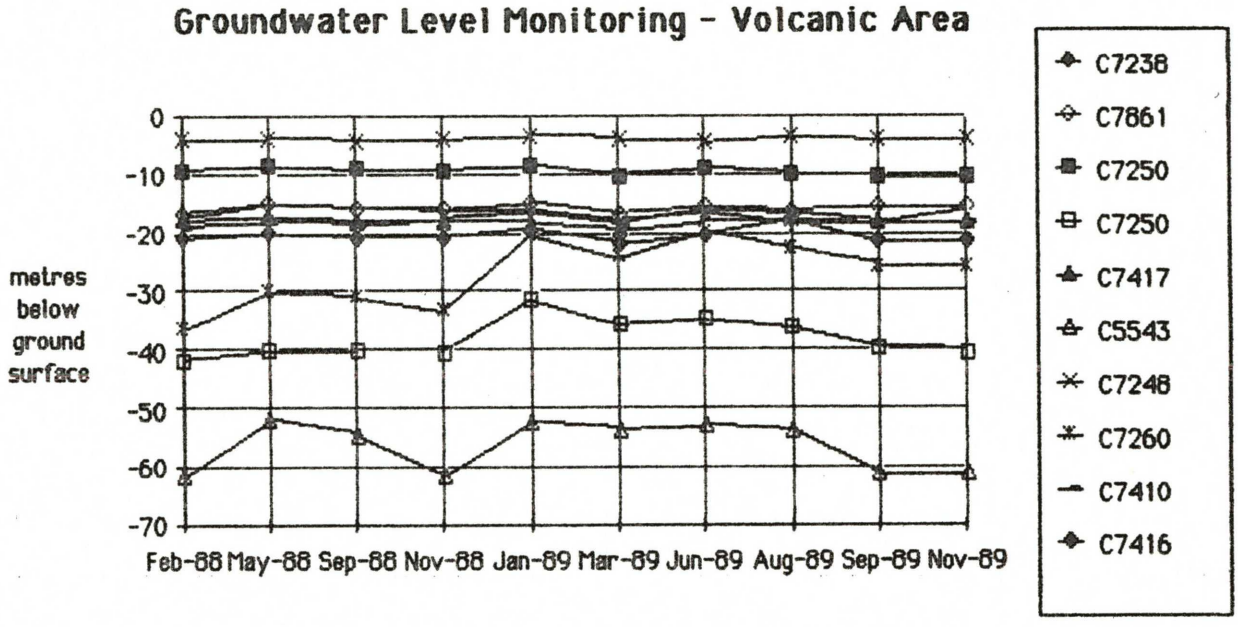
A total of 16 boreholes have been monitored (Table 5.4). Water level measurements were taken once per 2 to 3 month depending on the availability of transport. Most boreholes are equiped with handpumps. Pumping was stopped for at least 12 hours before the measurement was taken. The hydrographs show three effects:

1. the fluctuations are seasonal with the lowest levels in September-November and March: the groundwater levels respond to the rainy seasons.
2. fluctuations in the shallow boreholes are less pronounced than in the deeper ones
3. the response is a bit delayed. The delay in the two deepest boreholes in the period November 89 to February 90 was two months. These two boreholes are C7417 and C7414; they have the deepest waterlevels in the volcanic area and Basement area respectively.

Of the 25 boreholes drilled by SIDA during the past three years, five were dry and two abandoned due to caving. The yield of the remaining boreholes varied between 0.07 and 3.3 l/s.

Table 5.4 Groundwater Level Monitoring

BH NO	LOCALITY	FEB 8TH TO 10TH 1988 DEPTH (M)	MAY 25TH TO JUNE 1ST 1988 DEPTH (M)	SEPT 1ST TO 4TH 1988 DEPTH (M)	NOV 10TH TO 14TH 1988 DEPTH (M)	JAN 19TH TO 22ND 1989 DEPTH (M)	MARCH 24TH TO 27TH 1981 DEPTH (M)	JUNE 18TH TO 20TH 1989 DEPTH (M)	AUG. 9TH TO 18TH 1989 DEPTH (M)	SEPT. 26TH TO OCT. 1ST 1989 DEPTH (M)	NOV 14TH TO 21ST 1989 DEPTH	DEC. 14TH TO DEC. 22ND DEPTH	FEB. 22ND TO FEB. 28ND DEPTH
C6967	Maua Stadium	17.54	15.07	15.53	16.30	16.03	18.10	16.48	18.44	18.35	15.63	14.1	15.90
C7238	Athiru Gaiti Primary School	16.58	15.12	15.70	16.06	14.73	16.61	15.46	16.21	15.48	15.47	14.8	14.83
C7861	Kilili Primary School	9.35	8.62	9.18	9.27	8.38	10.23	8.89	10.12	10.49	10.47	9.12	8.64
C7250	Mutyandui Primary School	41.83	40.32	39.96	40.35	31.47	35.70	34.66	36.06	39.65	40.45	-	31.35
C7258	Kathithine	17.86	17.30	18.05	18.01	18.24	19.54	17.86	17.70	18.17	18.22	18.47	17.04
C7417	Ntuene Primary School	61.71	51.86	54.58	61.79	52.46	53.68	52.89	53.84	61.20	61.18	-	52.51
C5543	Ruiri	31.00	30.70	30.96	31.22	30.25	30.47	30.43	30.49	31.49	31.45	29.14	28.18
C7309	Kamaguna	3.94	2.18	4.03	3.18	3.07	3.48	3.45	3.87	3.42	3.40	-	3.24
C7314	Materi Girls Centre	16.68	12.75	15.47	13.55	12.05	12.84	10.83	11.90	12.81	12.79	8.9	10.72
C7136	Marimanti Health Centre	6.06	5.30	6.14	5.31	5.05	5.90	5.40	5.78	6.45	6.43	5.15	5.33
C7310	Marimanti Market	7.26	6.62	7.17	6.47	5.45	7.22	6.83	7.07	7.43	7.40	6.3	6.71
C7139	Gatunga Primary School	5.32	4.70	5.41	4.72	4.34	5.20	4.46	4.59	Filled with soil	Filled with soil	-	-
C7138	Gatunga Market	4.02	3.76	4.30	4.07	3.42	4.11	4.50	3.55	4.03	4.00	3.42	3.42
C7248	Tumu Tumu	36.50	30.06	30.98	33.46	20.53	24.24	19.80	22.65	25.81	25.80	15.3	18.86
C7260	Kianda Health Centre	18.84	18.14	18.68	17.59	16.47	18.40	15.97	16.75	18.16	18.15	15.92	14.79
C7410	Ugoti Primary School	21.10	20.13	20.71	20.87	19.46	21.83	20.33	17.83	21.52	21.49	-	20.37
C7416	Riigi	52.10	50.78	52.03	52.39	51.29	-	-	-	-	-	-	50.57
C7414	Kathangacwe	5.74	-	-	5.31	-	-	-	-	-	-	-	-



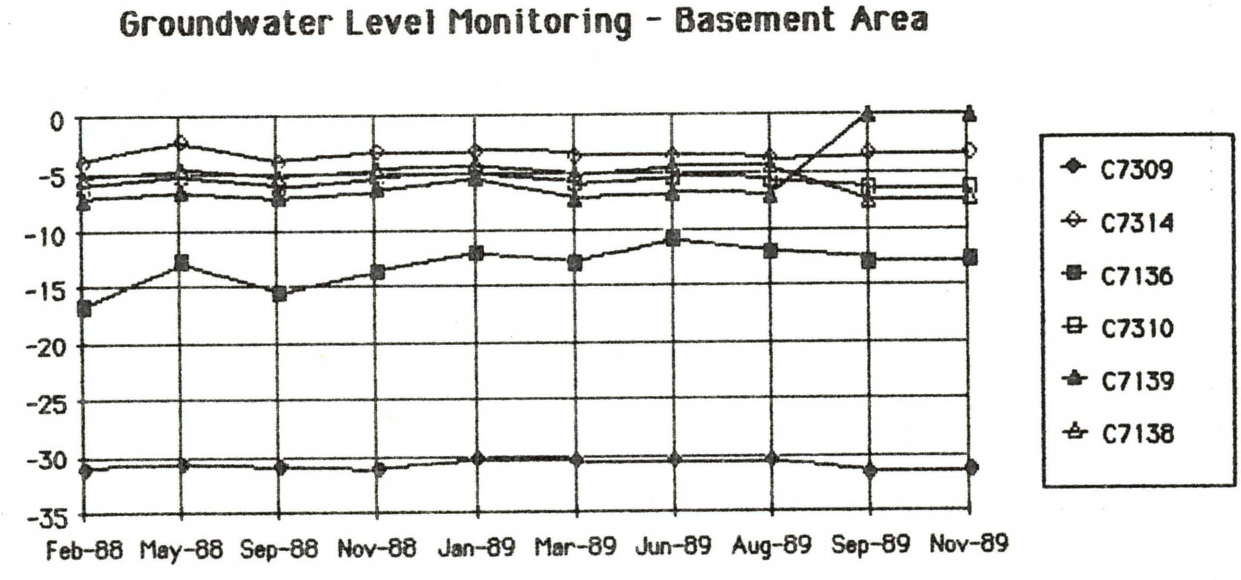
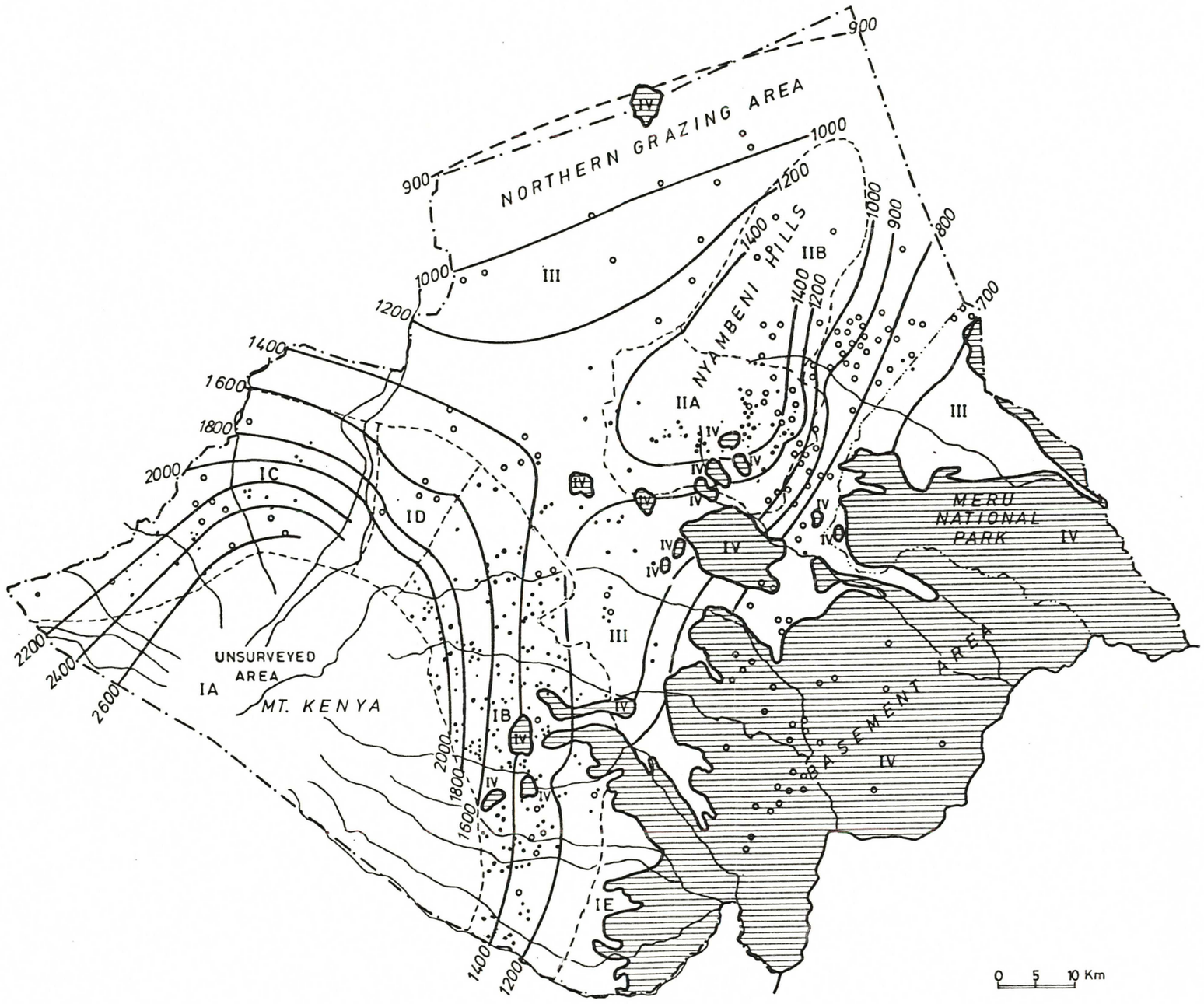


Figure 5.3 Groundwater Level Fluctuations

MERU DISTRICT



LEGEND

- District boundary
- National Park boundary
- River
- IIA Hydrogeological zone IIA
- Boundary between hydrogeological zones
- Basement area
- Spring
- Borehole
- 1000 Groundwater level contour

Fig. 5.4 Groundwater level contours

5.6 Groundwater Flow

5.6.1 Groundwater Flow Pattern

Two important regional groundwater recharge areas can be distinguished in Meru District, viz: the Mount Kenya area in the south-east and the Nyambeni hills in the west.

Groundwater in the Mount Kenya area flows in more or less radial directions to lower topographical areas around the mountain (see the groundwater elevation contours (Figure 5.4). A similar pattern can be observed around the Nyambeni Range where groundwater recharged in the higher regions flows towards the lower lying plains surrounding the hills. From the groundwater elevation contours it can be concluded that water infiltrating north of the theoretical line between the crests of both mountain ranges towards the north, while water infiltrating south of this line chooses a southern direction.

Only a part of the groundwater infiltrated in the recharge areas reaches the plains around the mountains as groundwater. The majority of it discharges through springs or as seepages into the small streams that join the tributaries of the Ewaso Nyiro in the north or the branches of the Tana River in the south. The volcanic aquifers north of the mountain ranges allow a more or less continuous groundwater flow. This situation is completely different in the south where the surfacing Basement forms an impermeable barrier for the groundwater flow, forcing it to discharge into the Tana River tributaries which cross the Basement area before reaching the main river.

The amounts of groundwater available for development can be deduced from groundwater recharge estimates by taking a safe percentage of the total recharge. The recharge in turn can be calculated from the groundwater flow leaving the recharge areas.

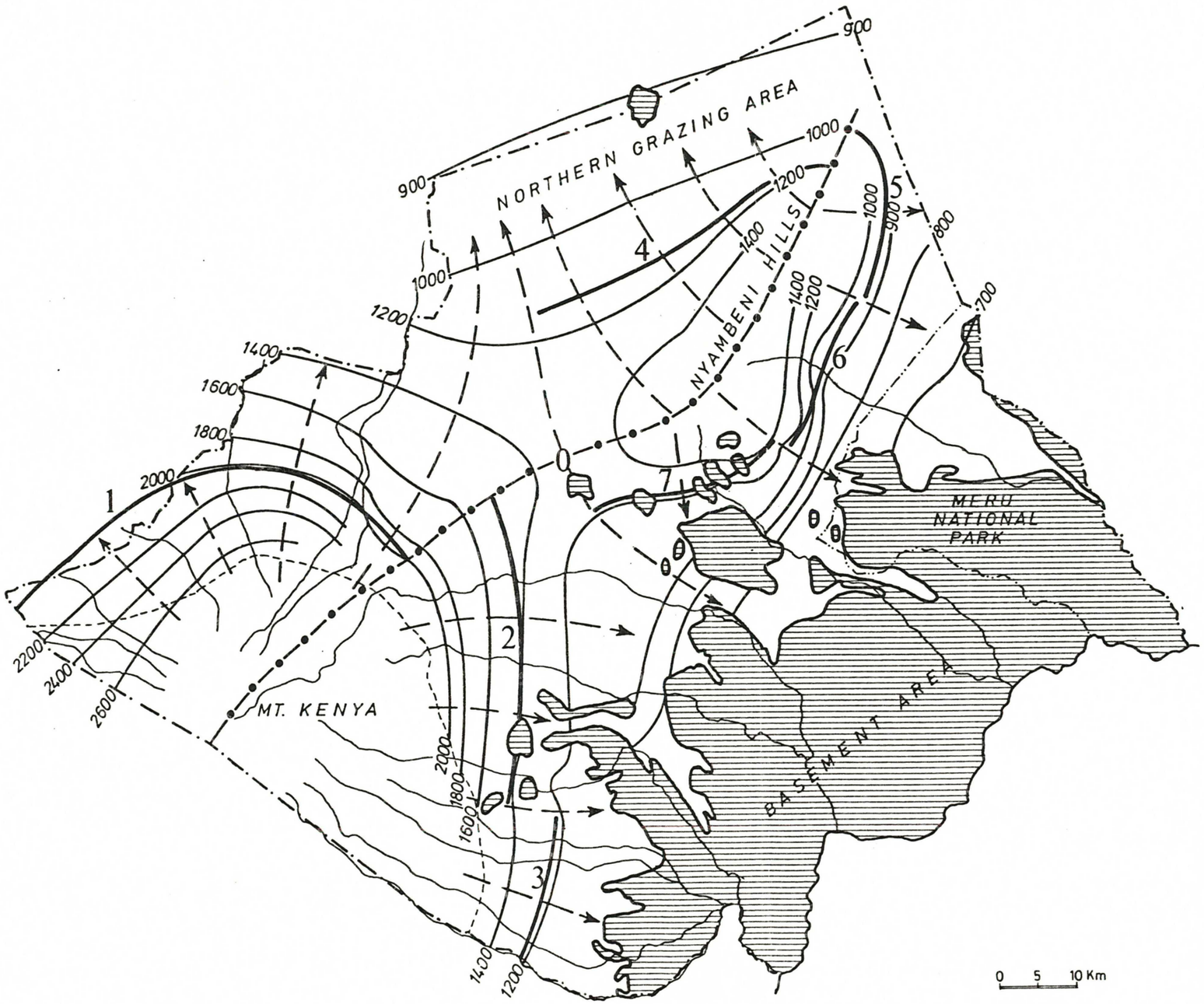
5.6.2 Groundwater Flow Calculations

For Meru District the groundwater flow was calculated for a number of sectors enclosing the recharge areas. These sections are depicted in Figure 5.5. The calculations are based on Darcy's formula and results are shown in Table 5.5. Transmissibilities have been estimated from pumptests in boreholes drilled by the Project.

Average transmissibilities are difficult to estimate, especially when insufficient data are available. These values are the most uncertain factor in the calculations and the calculated results should therefore be taken as rough estimates that might divert from reality by 30% or more.

Three flow sectors were used to calculate the groundwater flow from the northern and eastern side of *Mount Kenya*, one on the northern side and two to the south. It was not possible to carry out pump tests in the higher parts of the mountain. However based on experience average transmissibilities are believed to be in the order of 200 m^2/day. The volumes of groundwater flow resulting from the calculation amount to about 1.2 million m^3/day, which corresponds to about 18% of the average rainfall on the mountain assuming a recharge area of 2000 km^2 and an average annual rainfall of 1500 mm.

MERU DISTRICT



LEGEND

- District boundary
- National Park boundary
- River
- 1000 — Groundwater level contour
- Flow lines
- Groundwater divide
- Stagnation point
- 4 — Sector used for groundwater flow calculations

Fig. 5.5 Groundwater flow

5.7 Groundwater Quality

The chemical analyses of the water samples taken during the period 1987 until 1990 are listed in Appendix 5.4 while the Drinking Water Standards for Kenya are listed in Appendix 5.5.

The analyses were checked against the maximum permissable limits. The results are listed in the following table.

Table 5.6 Suitability of Water for Domestic Use

	Number	Unsuitable (all parameters)	Unsuitable (except pH, colour, Fe, Mn)
Springs	30	40%	3%
Wells	15	66%	13%
Water Supplies	23	61%	0%
Boreholes (Basement)	17	76%	29%
Boreholes (Volcanics)	94	45%	9%

The percentage of samples which are not suitable for human consumption varies between 40 and 76%. However, after stripping out the parameters associated with poor sampling procedures, poor borehole construction or long delays before the samples are analyzed (pH, colour, Fe, Mn) the numbers look different. The percentage of 9% of the samples from boreholes in the volcanics being unsuitable for human consumption looks too high. However, this number can easily be explained by the poor laboratory procedures as is evident from the ionic balances. The 'background noise' in the results is simply too high.

Water quality is only problematic in samples from the Basement Area. There is even one borehole (C7131) with a Fluoride concentration of 12 ppm while 3 ppm is the maximum permissable level and 1.5 the maximum acceptable level. The maximum permissable level is exceeded in 3 out of 17 samples while the maximum acceptable level is exceeded in 5 out of 17 samples.

Nevertheless, there is at least one spring, the Lanyiru spring in Tigania which is used as waterpoint. Many people, especially children dependant on this point suffer from fluorosis showing brown stains on their dents.

For livestock watering, the MoWD (1963) cites a TDS-limit of 5,000 mg/l for cattle and sheep and a Fluoride limit of 2.5 mg/l for dairy stock and 5 mg/l for beef cattle. Only 8 samples (4.5%) exceed the Fluoride norm for dairy stock while no TDS-value higher than the norm could be found. Therefore it can be concluded that a vast majority of the water sources in Meru District is suitable for cattle watering.

For irrigation sometimes a TDS of 1,000 mg/l and a SAR value of 10 is cited as being the limits for salt sensitive crops. Applying these limits yield 14 water points (8%) with a TDS of over 1000 mg/l render those waters unsuitable for irrigation of salt sensitive crops. Salt resistant crops can probably be irrigated without noticeable drawbacks with most water.

Table 5.5 Groundwater Flow

Sector	Width (m)	Gradient	Transmiss (m^2/day)	Flow (m^3/day)	Total Flow (m^3/year)
Mount Kenya					
1	53000	0.060	200	636 000	
2	38000	0.052	200	395 200	
3	18300	0.040	200	146 400	
				1177 600	$438*10^6$
Nyambeni Hills					
4	41700	0.013	1000	542 100	
5	35000	0.024	500	420 000	
6	22000	0.040	500	440 000	
7	22000	0.035	100	77 000	
				1479 000	$550*10^6$

Four sections were used to calculate the groundwater flow leaving the *Nyambeni Range*. Average transmissibilities are very different for the various sections surrounding the hills. Values of more than 200 m^2/day are found in the Northern Grazing Area, but for the northern foot hills of the Range 1000 m^2/day seems a more realistic value. For the south-eastern lower slopes of the Range 500 m^2/day has been chosen as an average T-value, and only 200 m^2/day for the southern side where the volcanics are relatively thin. The volumes of groundwater flow resulting from the calculations amount to about 1.5 million m^3/day which represents about 24% of the average rainfall on the Nyambeni area assuming a recharge area of 1500 km^2 and an average annual rainfall of 1200 mm.

As these calculations are very rough and the effects of withdrawal are difficult to foresee, the exploitation of groundwater should be undertaken stepwise, gradually increasing the abstractions while continuously monitoring the effects.

5.6.3 Comparison of Groundwater Flow and Baseflow

Major rivers flowing in the lowest parts of the area tend to collect the major part of the groundwater discharge from the catchment showing it as baseflow in their hydrographs. Hence baseflow analysis, if based on reliable data may produce a very good estimate of the groundwater flow in an area.

Baseflow hydrograph have been analysed for all catchment in Meru District with adequate discharge records. The results show that the average baseflow for a dry season of 3 months amounts to 45 mm. For a wet season the baseflow may be at least 50% higher. The annual baseflow for the volcanic area of Meru District should therefore be in the order of 225 mm/year or more corresponding to at least 20% of the annual rainfall.

The above percentages correspond very well with the percentages obtained from groundwater calculations.

6. WATER RESOURCES

6.1 Introduction

The occurrence of water in Meru is controlled by climatology, topography and geology (Chapter 4 and 5). As a result, water is unevenly distributed over the area.

For the evaluation of the available resources, both the amount and the quality of the water must be taken into account. And, in the case of groundwater, also the depth below groundsurface.

The 1963 study of the Ministry of Works into the water resources of the Ewaso Ngiro Basin concluded that 'there is more land suitable for irrigation than can be irrigated by available surface water but that substantial untapped resources of groundwater exist which could be developed beneficially, particularly in ranching, mixed farming and semi-arid areas' and 'that the natural river flows must be controlled if the water is to be made available where and when it is needed. In addition, the report recommended that 'a much greater use should be made of subsurface water for stock and domestic supplies' and that 'it will be necessary to construct dams in the upper catchment to regulate flows and to conserve flood waters for use in the dry season when irrigation needs are greatest'.

The Water Resources Assessment Study was aimed at studying in more detail the regimes and capacity of both the surface water and the groundwater systems. The results are an essential component for the planning of water management and water exploitation in the District.

6.2 Water Resources Availability

6.2.1 Surface Water Availability

The higher parts (above 1500 m) of Mt Kenya and the Nyambeni Range are the most productive areas for streamflow generation, mainly because of the high rainfall (Plate 1). In addition, rainfall is rather evenly distributed over the seasons, infiltration conditions are favourable and aquifer transmissibilities high. Groundwater emerges in numerous springs and seepages (the spring inventory identified around 560 springs, but there are more in the unsurveyed areas), often discharging in riverbeds. As a result, most of the streams sustain high, steady baseflows.

There are however two areas situated above 1500 m without surface water: i.e. the Kirua-Kibirichia and the Lare area. These are areas covered by many recent parasitic cones. Infiltration capacities are very high and aquifers very deep. There are no springs in these areas to feed the rivers during dry periods. Rivers therefore are ephemeral. Elsewhere streamflow production is largely confined to the rainy seasons. The surface water availability is depicted in Figure 6.3.

The available streamflow data from 26 hydrometric stations in Meru District were used to estimate the total streamflow generated in Meru District and the total surface flow from Mt Kenya in Meru District along the Chuka-Meru-Nanyuki road. The results are given in Table 6.1 and depicted in Figure 6.1 and 6.2.

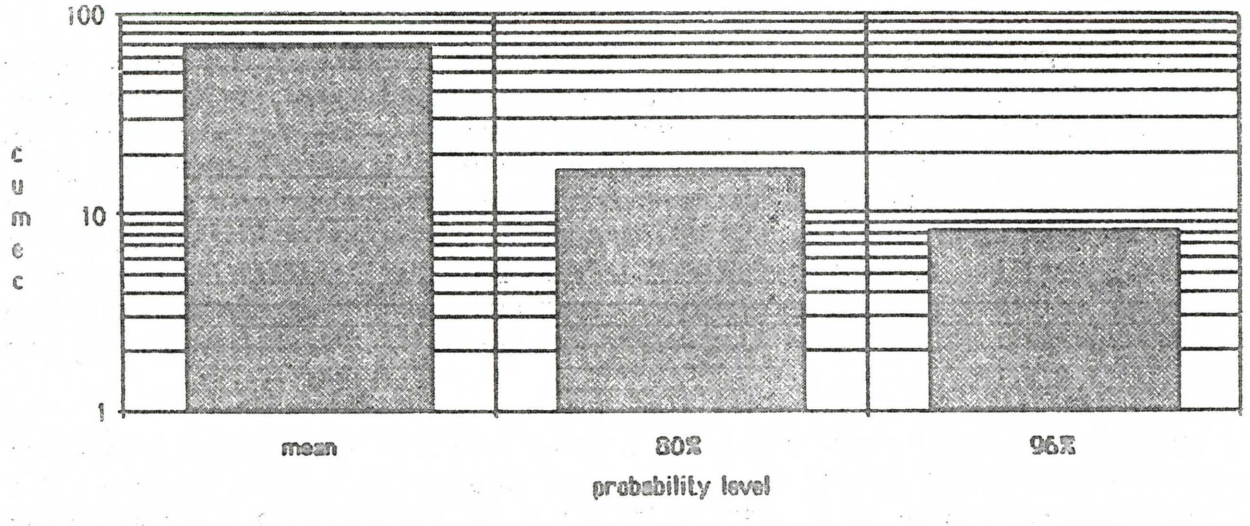


Fig. 6.1 Streamflow, generated in Meru District, flowing into the Tana River

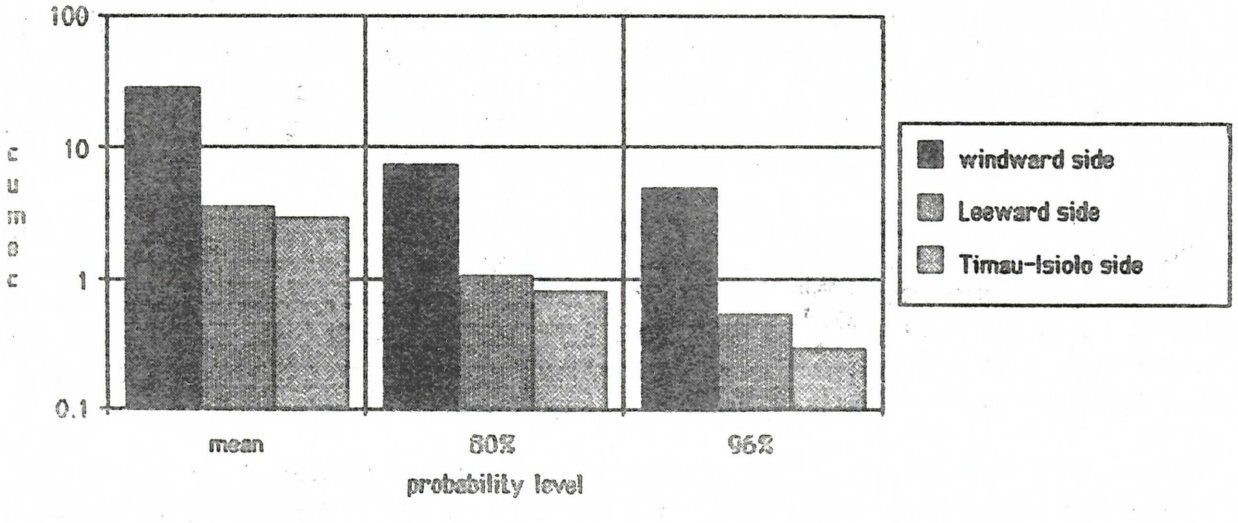


Fig. 6.2 Streamflow, generated on Mt. Kenya, passing the Chuka Nanyuki Road

Table 6.1 Summary of streamflow in Meru District

			mean	80%	96%	
Streamflow into the Tana River			70	17	8	cumec
Streamflow into the Ewaso Ngiro Basin			10	3	2	cumec
Total Streamflow generated in Meru District			80	20	10	cumec
Streamflow along the Chuka-Nanyuki Rd	Mt Kenya, windward side	4E	29	7.6	4.9	cumec
	Mt Kenya, leeward side	5BE	3.6	1.1	0.5	cumec
	Mt Kenya, Timau-Isiolo side	5D	3.0	0.8	0.3	cumec
Total streamflow passing the Chuka-Meru-Nanyuki road			36	10	5.7	cumec

Note: there are no reliable measurements available for the estimate for the Timau-Isiolo side

The expected overall domestic demand for the year 2013 of 2.4 cumec (see chapter 1.8) can easily be accommodated by the streamflow available at a 96% probability level. Nevertheless, there are areas in Meru District, like the Northern Grazing Area, without permanent rivers. In these areas groundwater is the only viable alternative.

The chemical quality of surface water is good for domestic use, cattle watering and irrigation.

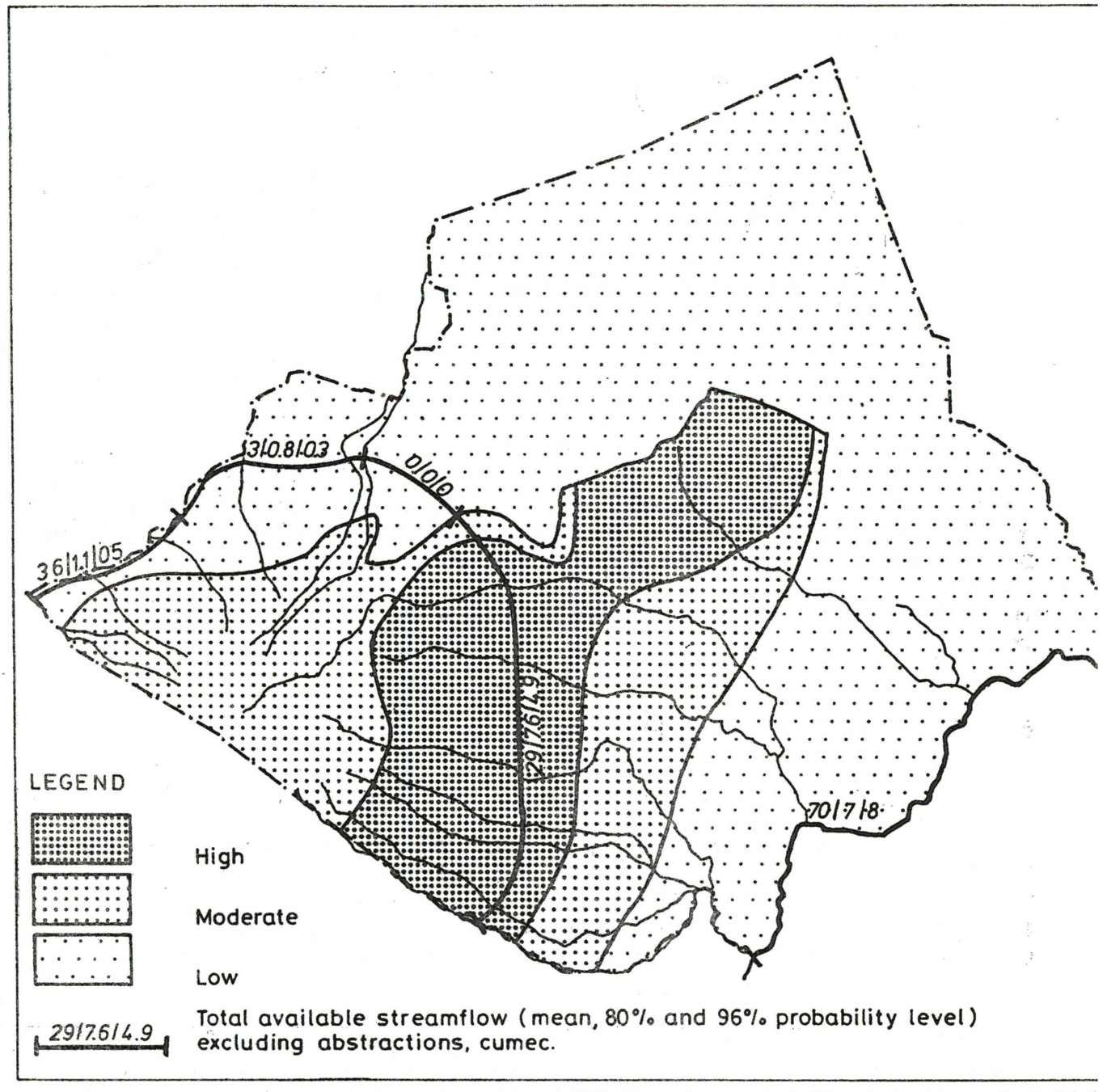
6.2.2 Groundwater Availability

General Situation

The subsoil of Meru consists of two major units: the Basement System and the Tertiary Volcanics. Groundwater is found in both units and in the shallow alluvial sediments on top of these units. The Basement System is characterized by the presence of local aquifers: this means that there are many small, isolated groundwater pockets in this unit that usually coincide with fractured and/or weathered zones. Borehole siting is therefore critical in the Basement Rocks.

In contrary, the Tertiary Volcanics form a predominantly regional aquifer. The parts above the 1500 m contour are characterized by systems of cascading perched aquifers: infiltrating groundwater flows downward to the main aquifer. On its way, it encounters impervious layers (e.g. lava flows or dikes). Groundwater tends to accumulate on top of such layers giving way to the formation of perched aquifers. Springs can be expected where these aquifers come close to the ground surface. Borehole yields of such small, local systems tend to be low. Borehole siting is critical and should be done by an experienced hydrogeologist as there are no geophysical methods to find such perched aquifers.

Perched aquifers are missing in the two zones with recent parasitic volcanic activity: the Lare and Kibirichia-Kirua areas. Here, infiltrating groundwater percolates downward unhindered by impervious layers. It is highly likely that these zones are underlain by very productive aquifers at greater depth.



HIGH	High Rainfall: >	1400 mm/y in areas lower than 1500 m +MSL
	>	1200 mm/y in areas higher than 1500 m +MSL
		Major Streams with minimum flow > 100 l/s
MODERATE	Intermediate Rainfall	800-1200 mm/yr in areas lower than 1500 m +MSL
		1000-1400 mm/yr in areas higher than 1500 m +MSL
		Major Streams permanent
LOW	Low Rainfall <	1000 mm/year in areas lower than 1500 m +MSL
	<	800 mm/year in areas higher than 1500 m +MSL
		Major Streams Ephemeral
		(streams are only permanent if they rise in other zones)

Figure 6.3 Surface Water Availability

Below the 1500 m contour, there is a continuous aquifer in most of this unit: it is likely that a major part of the water discharged by the springs near the Ewaso Ngiro comes from the higher parts of Mt Kenya or the Nyambeni's.

Baseflow analysis indicates that the average baseflow generated during a normal dry season of 3 months amounts to about 45 mm. For a wet season the baseflow may be at least 50% higher. The annual baseflow for these areas should, therefore, be in the order of 225 mm or more.

The baseflow generating area roughly encompasses the volcanic area minus the semi-arid volcanic plains. This area of about 4800 km² produces a total calculated baseflow of 1,082 million m³ per year or 34.3 cumec. The results correspond well with those obtained from the groundwater flow calculations (see chapter 5.6.3)

For a first phase of groundwater development a groundwater abstraction of 30% of the estimated groundwater recharge can be taken as a safe yield. As it may be assumed that the average groundwater recharge equals the total of discharge components (including baseflow and evapotranspiration) it is safe to take 30% of the baseflow as a basis for groundwater development.

This amount of groundwater available for a first phase of development would be sufficient to sustain more than 3000 boreholes of 10 m³/hour.

Groundwater availability can be subdivided into five zones with respectively: (i) Very High, (ii) High, (iii) Medium, (iv) Low and (v) Uncertain Groundwater Availability. The characteristics of the zones regarding groundwater availability are summarized in Plate 2, and described underneath:

(i) Areas of Very High Groundwater Availability

The aquifers are continuous in this area while the yields of the exploratory boreholes drilled by WRAP are very high, much higher than the old ones. The most productive aquifers are found in pyroclastics (cinders, clean (=no clay) coarse pyroclastics and weathered basalts, etc). Yields of properly constructed boreholes, like the ones drilled by WRAP, will be very high, possibly around 50 m³/h, or even substantially higher with 20 or 30 inch diameter holes. Using such boreholes, irrigation with groundwater is feasible.

Volcanic Plains: The recharge potential is very good; most recharge comes from the higher parts of the Nyambeni, and to a lesser extent Mt Kenya. Average yield of existing boreholes is high. Groundwater struck levels are rather shallow as are groundwater rest levels and borehole depths. Groundwater quality in these volcanic rocks is usually very good.

There are only 56 permanent springs in this area but their average discharge is high.

(ii) Areas of High Groundwater Availability

These areas are endowed with numerous springs of good quality water. These sources should be preferred instead of boreholes for reasons of economy and reliability. Where no springs are available, boreholes can be used: yields are rather high and siting is not critical. Often, aquifers are perched; the most productive aquifers are found in cinderlayers. Recharge potential is very good. Aquifers are continuous and hydraulically interconnected by fissures

Windward Mount Kenya Slopes (Meru-Chuka Area): There are only 11 boreholes in this area, mainly because of the large number of springs. During the spring survey, 360

permanent springs were found. Borehole yields are rather high as is the success rate. The average groundwater struck levels is 53 m. Groundwater quality in these volcanic rocks is usually good and suitable for domestic use and irrigation.
The average spring discharge is high while the chemical quality is excellent.

Nyambeni Hills: There are only 13 boreholes in this area but a large number (117) of permanent springs. The average spring discharge is high.

The average spring discharge is high while the chemical quality is excellent.

(iii) Areas of Medium Groundwater Availability

Leeward Mount Kenya Slopes (Nanyuki-Timau Area): There are only 37 springs with good quality water: the spring density is much less than in the rainier windward side but the yields are high. The use of springs instead of boreholes should be preferred. There are 11 boreholes in this area but only eight are successful. Groundwater rest levels are rather deep and borehole yields are medium. As almost everywhere else in the volcanics, siting is not critical while the most productive aquifers are found in cinderlayers. The recharge potential is good and aquifers are continuous and hydraulically interconnected by fissures.

Groundwater quality in these volcanic rocks is good, suitable for both domestic use and irrigation.

(iv) Areas of Low Groundwater Availability

Compact Tuff Area: Groundwater in this area occurs mainly in fine volcanic tuffs, and and lava flows. There are no permanent springs. Borehole yields are very small, only sufficient for handpumps and borehole siting is not critical. Groundwater struck and rest levels are near the ground surface. Water quality is expected to be generally good enough for domestic use

Basement Area: Groundwater occurs mainly in fractures, faults and in weathered zones forming small, isolated water bearing cells of low permeability: groundwater quantities are usually small. Borehole siting therefore is critical: proper application and interpretation of geophysics could improve the success rate of boreholes. Boreholes should be near rivers or laggas so as to facilitate recharge. Borehole yields are low (3.113.0 m^3/h) but water struck and rest levels are shallow.

Groundwater quality is not good: usually mildly saline to very saline, and hard to very hard. Fluoride levels often exceed the standard of 2.5 mg/l.

The overall success rate of boreholes is about 30% taking into account sufficient discharge for a handpump and the permissable chemical concentrations.

There are no permanent springs.

(v) Areas of Uncertain Groundwater Availability

Kibirichia & Lare Area: Groundwater probably occurs in large amounts at greater depth (>200 m), but how deep is not known. Perched aquifers with sufficient yield for handpumps do occur sometimes at shallower depth: in the Lare area, only two out of a total of 13 boreholes have a discharge which is sufficient for handpumps. There are

very few permanent springs. Borehole siting is not critical; striking a perched aquifer seems to be a matter of luck.

Water quality is expected to be generally good enough for domestic use but there are no data.

6.3 Water Resources Development Potential

6.3.1 Surface Water Development Potential

There is ample potential left in Meru District for development of surface water, for domestic use and even for development of low flows for irrigation. Construction of additional streamflow intakes for irrigation can be considered.

The available low flow with a probability level of 80% (design flow for irrigation projects) of 20 cumec (equals around 630 million m^3/year) is sufficient to irrigate an area of about 200 km^2 given an irrigation requirement of about 10 mm/day. This acreage could be substantially increased with proper storage facilities (dams) along the main rivers.

In some of the semi-arid areas of Tharaka where the distance to the nearest perennial stream is too large, sub-surface dams and sand-filled dams in the beds of seasonal rivers may provide reliable water points, particularly for cattle watering. Roof catchments can be an important supplementary source of drinking water provided that the storage tank is properly constructed.

However, the chemical and biological quality of the streams is in danger as more than 100 coffee factories dispose their effluent without proper treatment into the rivers. Unfortunately, peak coffee production coincides with the onset of low flows when dilution is not as strong as during the rainy season. So, the poisonous coffee effluent is discharged into the streams in a time when about 70% of the population depends on river flow for their drinking water. Only strict law enforcement by curbing illegal waste water disposal could alleviate this situation.

6.3.2 Groundwater Development Potential

Large parts of Meru District have more than sufficient surface water to satisfy present and future demands. Baseflow in many of these areas originates from spring water which ensures a permanent supply throughout the dry season. Groundwater supply from boreholes is then an expensive alternative which may not be economically feasible for many types of use. However, where the quality of surface water is unsuitable for domestic use during a large part of the year, groundwater supply from springs, boreholes or dug wells should be considered. The benefits in the form of reduced incidence of illnesses may outweigh the high costs of construction or treatment.

In the eastern slopes of Mount Kenya and the western part of the Nyambeni Uplands springs are almost everywhere and as such their development is preferred.

In the leeward slopes of Mount Kenya and the Volcanic Plains (including the Northern Grazing Area) where springs are few or non-existent, water supply from boreholes is considered generally feasible for domestic use.

Only the Kibericha-Kirua and the Lare Areas lack surface water. Groundwater is extremely deep and development is considered highly questionable.

In the Tharaka Basement Area the only option for groundwater supply is drilling of boreholes. There are many local aquifers with limited supply capacity and water of acceptable quality, but their siting requires hydrogeological and geophysical surveys.

REFERENCES

Archer, G.F. 1973

Recent Exploration and Survey in the North of British East Africa
Geological Journal vol. 42, 421-430

Baker, B.H. 1947

Geology of Mt. Kenya Area
Geological Survey of Kenya Report No. 79
Government Printer, Nairobi

Broun W.H., 1906

A Journey to the Lorian Swamp, British East Africa
Geological Journal vol. 27 pp 36-51

Dodson R.G. 1955

Geology of the North Kitui Area
Geological Survey of Kenya, Report No. 33
Government Printer, Nairobi

Gregory, I.W. 1900

"Contributions to the Geology of British East Africa, Part II.
The Geology of Mt. Kenya"
Quart. Journal.
Geological Society of London LV1 pp 205-222

Jennings, B.J. 1967

Geology of the Archer's Post Areas
Geological Survey of Kenya, Report no. 77
Government Printer Nairobi

Mason P. 1955

Geology of the Meru-Isiolo Area
Geological Survey of Kenya, Report no. 31
Government Printer, Nairobi

Ministry of Finance and Planning

Meru District Development Plan, 1984-1988
Meru District Development Plan, 1989-1993

Ministry of Water Development, 1968

Water Resources Assessment Study in Laikipia District

Ministry of Water Development, 1987

Water Resources Assessment Study in Laikipia District

Ministry of Works, 1963

An investigation into the Water Resources of the Ewaso Ng'iro Basin, Kenya
Hydraulic branch Report no. 4

Rix P. 1967

Geology of the Kinna Area
Geological Survey of Kenya, Report no. 81
Government Printer, Nairobi

Schoeman, J.J. 1951

A Geological Reconnaissance of the Country between Embu and Meru
Geological Survey of Kenya, Report no. 17
Government Printer, Nairobi

Schackleton, R.M. 1946

Geology of the Country between Nanyuki and Maralal
Geology survey of Kenya, Report no. 11
Government Printer, Nairobi

Williams, L.A.J. 1966

Geological of the Chandller's Falls Area
Geological survey of Kenya report no. 75

Tole M.P. and M'Ragwa - 1987

The sweet waters of Meru
Unpublished paper