REPUBLIC OF KENYA



MINISTRY OF WATER DEVELOPMENT

WATER RESOURCES ASSESSMENT STUDY

IN

LAIKIPIA DISTRICT

MAIN REPORT

MAY 1987

WATER RESOURCES ASSESSMENT DIVISION
NAIROBI, KENYA

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SUMMARY

The Water Resources Assessment Project

The Water Resources Assessment Project carried out a water resources assessment study of Laikipia as part of the co-operation between the Ministry of Water Development and the TNO-DGV Institute of Applied Geoscience, the Netherlands. This summary gives a brief account of the results of the investigations with emphasis on the potential for water development.

Project Area

The area of investigations is bonded by the parallels 0° 20'S and 0° 45'N and the longitudes 36° 15'E and 37° 20'E (Figure 1.2). The surface water investigations are basin-oriented, covering the Upper Ewaso Ngiro Basin upstream of the confluence of the Ewaso Ngiro and Ewaso Narok. (7851 km²). Nevertheless, data from Archer's Post with a drainage area of 15 300 km² have also been used.

Groundwater investigations focus on Laikipia District (9723 km²) although some attention is paid to the upper parts of the basin situated in Ngeri and Meru District. The current (1987) population of the District is estimated at 215,000.

The Ewaso Ngiro Basin is bounded to the south-east by Mount Kenya (5,199 m) and to the south-west by the Aberdares (3,999 m). The central part of the basin is rather flat: this is the area of the Nanyuki and Rumuruti plains (1,500-2,000 m) which are underlain by lavas.

The Ewaso Ngiro river system rises on these volcanic edifices from a great number of small perennial streams. The dominant direction of flow of the Ewaso Ngiro river system is to the north. One lake (Lake Ol Bolossat), five large and numerous small swamps are situated along the river system, of which the Ewaso Narok and Pesi swamps are the most important.

The geological base of Laikipia consists of Precambrian metamorphic rocks outcropping in the Mugogodo area. In the rest of the area they are overlain by Tertiary and Quarternary lavas interbedded with tuffs and sediments. The eastern part of the district, situated on the escarpment, is intensively faulted and fractured. Recent sedimentary deposits are restricted to small strips along the rivers.

Soils in Laikipia are generally medium to highly fertile: fertility is not a major limiting factor for cultivation but water is. Shallow stony soils with rock outcrops prevail in the semi-arid part of the area.

The climate is strongly associated with altitude. It is arid at altitudes of less than 1,600 m and semi-arid from 1,600-2,000 m (Figure 1.3 and Plate 4.1). Rainfall in the semi-arid zone is generally less than 700 mm while evaporation is more than 1,800 mm. The humid and semi-humid highlands experience rainfalls of over 1,000 mm and evaporation of less than 1,500 mm. In between the semi-humid and semi-arid zone is a transitional zone. 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.

Investigations

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

Water Supplies

A water survey was held in 1986 during which 86 water supply systems were visited, while in the beginning of 1987 a water permit inventory was carried out to obtain information on the legal water abstractions.

Most water supplies in Laikipia District are based mainly on surface water. Nearly 90% of the population depends on such systems (Figure 6.1a). Other types of water supplies are based on boreholes, springs, wells, dams and rock catchments, or a combination of these.

Valid surface water permits are issued for 621 different abstraction points along the rivers, endorsing a total dry season abstraction of 1.4 cumec above the Junction of the Ewaso Narok and the Ewaso Ngiro. This is more than three times the level reached in the early 1960s, which was 0.4 cumec.

There are 120 operational boreholes, mainly on the ranches, which supply water for both domestic and livestock use. These boreholes are concentrated in the Central Division, between Nanyuki Town and the Pesi Swamp. Water is also obtained from springs in Central, Rumuruti and Ng'arua Divisions. In Mukogodo Division, during the dry seasons, water is obtained from hand-dug wells in the riverbeds.

The water survey counted 137,000 people, 180,000 sheep and goats, and 152,000 heads of cattle that are served by the water supply systems. These numbers deviate substantially from the corresponding census data: it is not clear whether this is due to errors of estimate, or that large groups are not being served by the inventoried systems.

Water Demand

Water demand projections for domestic use and cattle watering were made for the year 1987 and 2000, using the 1979-census for population and the 1983 figures for livestock estimates. Livestock can be expressed in LSU: livestock units. One livestock unit is equivalent to 2.5 cows, 20 goats or sheep, or 1.25 camels.

Water demand is specified as 25 litres/day/capita when served from communal water points at 50 litres/capita/day when served by individual onnections. One LSU (livestock unit) is assumed to require 75 litres/day. Total annual water demand is an estimated 4.6 Mm^3 for 1988 and 8.9 Mm^3 for the year 2000 (Table 6.3). 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. Demand for irrigation can only be satisfied from dams in which rainy season flows are stored.

Surface Water Resources

The higher parts (above 2,000 m) of Mount Kenya and the Aberdares are the most productive areas for streamflow generation. Here, rainfall is high and rather evenly distributed over the seasons. Infiltration conditions are favourable and aquifer are transmissibilities high. Groundwater emerges in many perennial springs and seepages, often in the river beds, thus becoming baseflow.

Elsewhere, streamflow production is largely confined to the rainy seasons.

The mean recorded mean streamflow at the confluence of the Ewaso Ngiro and Ewaso Narok amounts to 370 Mm^3/year, or 11.7 cumec. Due to the fact that floods tend to pass during the evening and night when no staff gauge readings are made, actual flows could be higher. However, most of this water is generated during the rainy seasons when demand is lowest. Without proper storage facilities these high flows remain unused.

Dry season streamflows are much lower. The 95% flows are generally used for the design of water supplies. Total discharge at this probability level, generated at the Upper and Middle Volcanic Slopes amounts to approximately 2.3 cumec. Including the Plateau there is only 1.2 cumec left and further down at the Junction only 1.0 cumec. This decrease is due to infiltration and abstractions. Including the legal abstractions, the corresponding flows amount to 3.2, 2.6 and 2.4 cumec respectively (Figure 6.2). Legal abstractions upstream of the Junction are up from 0.4 cumec in the early sixties to 1.4 cumec in early 1987 (Figure 6.4).

As a result, dry season abstractions have already reached a critical level: in 1985 and 1986 a 50 km stretch of the Ewaso Ngiro upstream of Archer's Post fell dry for several weeks, 1985 being the first time in living memory.

The quality of surface water is good for domestic purposes, cattle watering and irrigation. Only in Lake Ol Bolossat water is not potable, unsuitable for irrigation, and only marginally suitable for cattle.

Potential for Developing Surface Water

It is clear that very little, if any, potential is left for development of low flows. In particular this is true for irrigation for which peak demand coincides with periods of low flow. Strict law enforcement by curbing illegal abstractions could alleviate the situation during droughts and thus create some room for abstractions for domestic purposes.

The medium-to-high flows constitute the main source for further development of surface water. To meet demand when it is strongest, building of large storage facilities is the only solution. Each dam could service large-scale irrigation and fish production. A cost-benefit and social impact study for large scale irrigation goes beyond the scope of this report.

Groundwater Resources

In the volcanic part of the area a regional aquifer exists (Plate 5.1). Virtually every borehole strikes water provided that it is deep enough. Locally, e.g. in the Lariak-Sipili Region, water-struck levels are more than 250 m below surface. Only in the area east of Nyahururu, which is underlain by Thomson Falls phonolites, a number of boreholes, sunk to great depth, were complete failures.

There is no regional aquifer in the Basement area. Nevertheless, prospects for water development are favourable in the valleys, notably where deep sub-surface decay has produced thick zones of more or less permeable material. Elsewhere, prospects are not good although through careful geophysical surveys local small aquifers may be found.

The total amount of groundwater which is replenished annually in the catchment above the Junction is estimated to be in the range of 120 to 220 Mm^3. Most of this recharge (90%) however emerges as baseflow. But even if the recoverable amount of groundwater were only 5% of the recharge, the estimated present and future groundwater demand in Laikipia (0.9 and 4.5 Mm^3 respectively) can be easily met.

High potential areas are found on the Volcanic Slopes, most of which are situated outside the district boundaries, on Mount Kenya and the Aberdares (Plate 6.2). High-to-medium potential areas comprise the Nanyuki-Rumuruti-Sukuta Plains. In these areas, the mean water depth is 45 meters and the mean tested yield 5.7 m^3/h. Thus handpumps can be used almost everywhere. The Lariak-Sipili area and Basement area are classified as medium potential areas. In the former area, water depths are such that handpumps cannot be used. In the Basement only a part of the area is underlain by aquifers but water depths are such that water can be pumped by hand. The area east of Nyahururu is underlain by Thomson Falls phonolites and is classified as a low potential area because of the low yields, great water depths and the large number of failured boreholes. The intensily faulted and fractured area west of the watershed, situated in the Baringo and Bogoria catchments, is classified as variable because water depths and tested yields are expected to vary considerably.

Chemical quality is generally good but in 10 to 20% of the cases high salinity or high fluoride concentrations may make the water less suitable for human consumption.

Potential for Developing Groundwater

Prospects for further development in the high, high to medium and medium potential areas are favourable.

To meet the foreseen groundwater demand of 4.5 Mm^3/year by the year 2000, two options are available.

- **Submergible Pumps**

Assuming a mean annual production of 16,000 m^3 per well, a total of about 300 boreholes should be in operation by the year 2000. At present, 120 boreholes are being operated while 71 additional boreholes are in good condition and can be equipped with pumps. Furthermore, there are 23 boreholes which are blocked but can be cleaned and subsequently put into operation. So, approximately 100 additional boreholes should be made to meet the anticipated groundwater demand by the year 2000. Theoretically, 300 evenly distributed boreholes in this area of 9,000 km^2 imply a average distance between adjacent boreholes of 5 to 6 km.

- **Handpumps**

In most of the area, handpumps can be used. Assuming a annual production of 6000 m^3 per well a total of 750 boreholes must be in operation by the year 2000. This scenario requires that an additional 550 boreholes must be drilled. The average spacing between adjacent boreholes will be 3 to 4 km.

Groundwater rest levels in the Sipili - Kinamba area are so deep that hand-pumps cannnot be used. Fortunately, this area is relatively small.

Prospects to drill successful boreholes in the low potential area east of Nyahururu however are not good. Fortunately, the size of this area is small and use of surface water may be feasible.

The age of the groundwater in the volcanic area of 4,000 to 10,000 years indicates that recharge is low. Use of groundwater for irrigation seems therefore not feasible. Any groundwater development in this area should be monitored carefully if groundwater is developed beyond the scale foreseen above.

Conclusion

The studied area has sufficient potential to meet the current and future (year 2000) water demand. Water demand from domestic use and cattle watering can be met by drilling boreholes while technically speaking water demand from irrigation can be met by building large scale storage facilities in order to increase dry season flows. Current dry season flows are already overcommitted. Groundwater development in the Nanyuki, Rumuruti and Suguta Plains should take place in stages. Although the demand until 1990 would not affect adversely the storage, any development beyond the foreseen demand should be subject to additional study, as the age of the water suggests limited recharge.

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1. INTRODUCTION

1.1 Scope of the Project

This report deals with the regional assessment of the quantity and quality of the available water resources in Laikipia District, Rift Valley Province, which is almost encompassed by the upper Ewaso Ng'iro catchment area. The study has been executed within the framework of the Water Resources Assessment Project (WRAP), jointly carried out by the Water Resources Branch, Ministry of Water Development, Nairobi and TNO-DGV, Institute of Applied Geoscience, Delft, The Netherlands. Since 1981, the Water Resources Assessment Project has carried out regional assessment and reconnaissance studies (Figure 1.1). The names of the Kenyan and Netherlands project personnel are listed in Appendix 1.1.

The findings of this report are the result of hydrological, geophysical and hydrogeological investigations, carried out in Laikipia District between May 1984 and April 1987.

1.2 Description of the Project area

1.2.1 General

The area of investigation is bounded by the parallels 0° 20'S and 0° 45'N, and the longitudes 36° 15,E and 37° 20'E (Figure 1.2). Groundwater investigations are confined to Laikipia District (9,723 km²) but surface water investigations concentrate on the catchment area. The total drainage area for the lowest river gauging station on the Ewaso Ng'iro, SE3 at Archer's Post, situated circa 20 km downstream of the eastern side of Figure 1.2, is circa 5,000 km².

1.2.2 Physiography and Hydrogeography

Four main physiographic units can be distinguished:

(i) the volcanic edifices of Mount Kenya and the Aberdares;
(ii) the volcanic Central Laikipia Plateau;
(iii) the volcanic Footridges in the West, at the edge of the Rift Valley;
(iv) the strongly faulted and fractured western part of the District, draining to Lake Baringo
(iv) the Basement System Area in the north-west.

The volcanic edifices can be subdivided into: (i) the Upper, (ii) the Middle and (iii) the Lower Volcanic Slopes.

The Upper Volcanic Slopes of Mount Kenya are situated above circa 3,500m. This zone comprises a glacial-naval subzone, an afro-alpine subzone and a moorland subzone. Most glaciers drain into the Ewaso Ng'iro catchment area but contrary to the popular belief, total discharge from this area is small. The whole area is mainly a recharge area with probably a deep groundwater table, though locally shallow groundwater and moorlands occur which are associated with perched aquifers. A similar description holds

WATER RESOURCES ASSESSMENT PROJECT

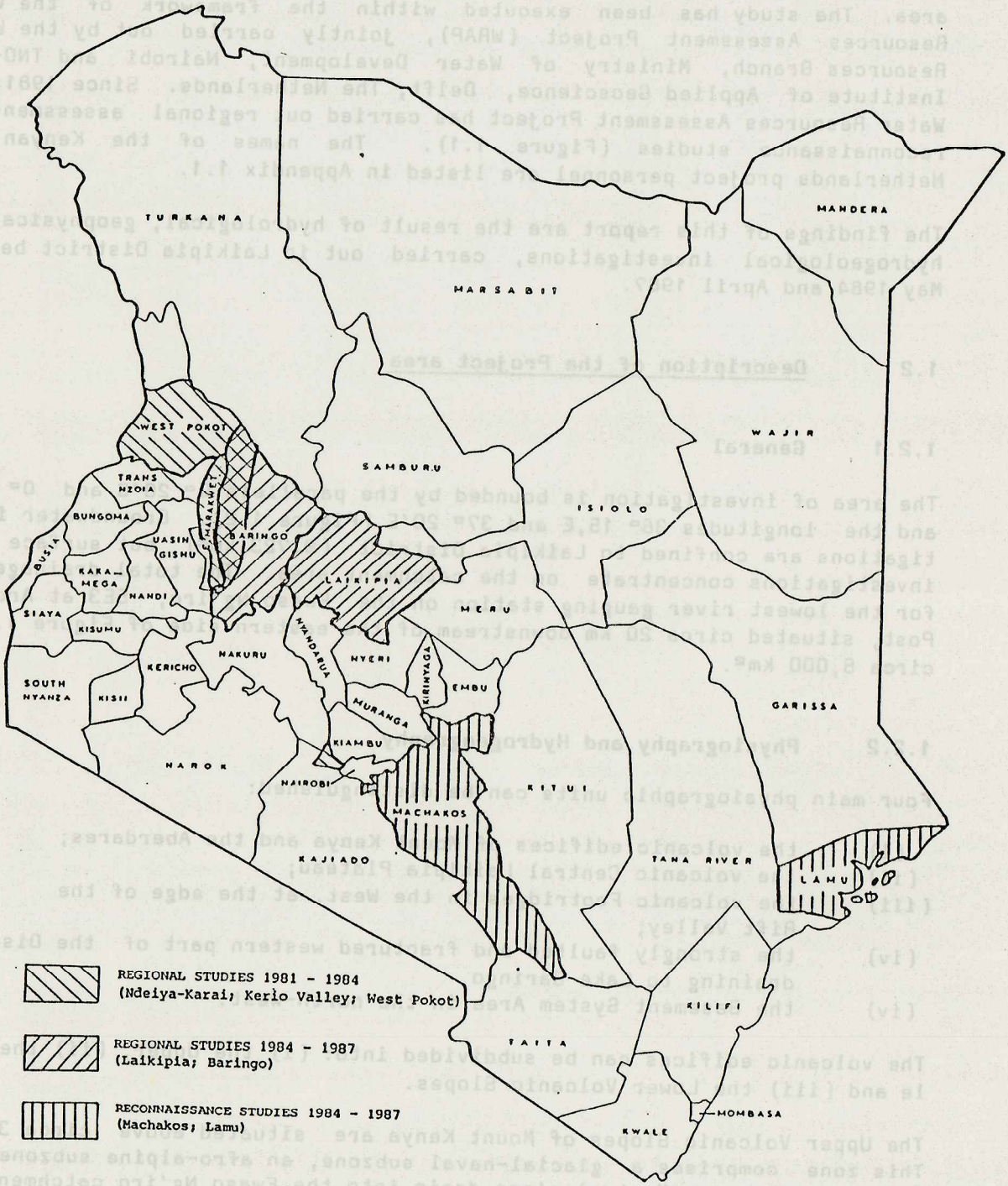


Figure 1.1 WRAP Regional Assessment and Reconnaissance Studies Executed Under the WRAP Programme 1981-1987

true for the Upper Volcanic slopes of the Aberdares though glaciers are absent as the elevation is lower (Figures 1.2 and 1.3).

The Middle Volcanic Slopes extend from circa 2,300m to circa 3,500 m on the Aberdares and the western slopes of Mount Kenya and from circa 2,500 to 3,300m on the northern slopes of Mount Kenya. They are covered with forests which tend to thin out to the north 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. On the Aberdares strong springs are more common than on Mount Kenya where diffuse effluence is a general feature.

The Lower Volcanic Slopes are used for rainfed agriculture. They are among the best lands in the area. The terrain is hilly to rolling though steep sloping rugged parts also exist. Stream incision generally decreases in a downstream direction as does rainfall. The landscape has a humid appearance in the upper parts of this zone and a semi-arid one in the lowest parts. The boundary with the arid Central Laikipia Plateau is of course quite arbitrary but the 2,000 m contour seems the best compromise. The groundwater table is predominantly shallow at the transition zone between the Upper and Middle Volcanic Slopes but falls gradually to greater depths in downstream directions. Few springs occur in this area and groundwater recharge is low due to lack of rainfall. It is predominantly a groundwater transfer zone with some recharge in the humid upper parts but little in the lower parts.

The Central Laikipia Plateau lies roughly between the 2,000m and 1,500m contour lines. Its climate is semi-arid. It is formed by lavas which have been extruded from the Aberdares and north of Mount Kenya. The topography is mostly flat to gently undulating with rivers flowing through narrow valleys. Its outer edge in the north is widely developed as an escarpment which locally reaches 70m.

The Basement System Area is considered as a separate unit. The appearance of the rocks and the terrain is very different from that in the volcanic areas as are the groundwater, surface water and climate conditions. The Basement Area can be characterised as a dusty, arid flat dotted with Inselbergs and bare, rugged mountains. Only north of the Central Laikipia Plateau there is a difference; there it is an extension of this plain being an rejuvenated immature peneplain.

After turning sharply east through the gap between the Mukogodo Hills in the South and the Karissia Hills in the north, the Ewaso Ng'iro flows through a locally 70m deep gorge in the middle of a circa 60 km long arid valley called Barselinga. This valley is dominated by high mountains to the north and the south. It is a severely eroded area with many sand rivers and sparse vegetation. Towards Archer's Post prominent inselbergs or monadnocks dot the valley, many of them standing 700m above the valley floor.

The volcanic footridges at the west of the study area coincide with the eastern edge of the Rift Valley. The Dundori Ridge (2,871m) is used for mixed farming, the Marmanet Ridge (2,608m) is forested and the Lariak Ridge previously used for ranching, is now subdivided and used for farming. To the north, in the Kinamba, Sipili and Olmoran Divisions, the climate is semi-arid to arid. The ridges are rather bare and rugged.

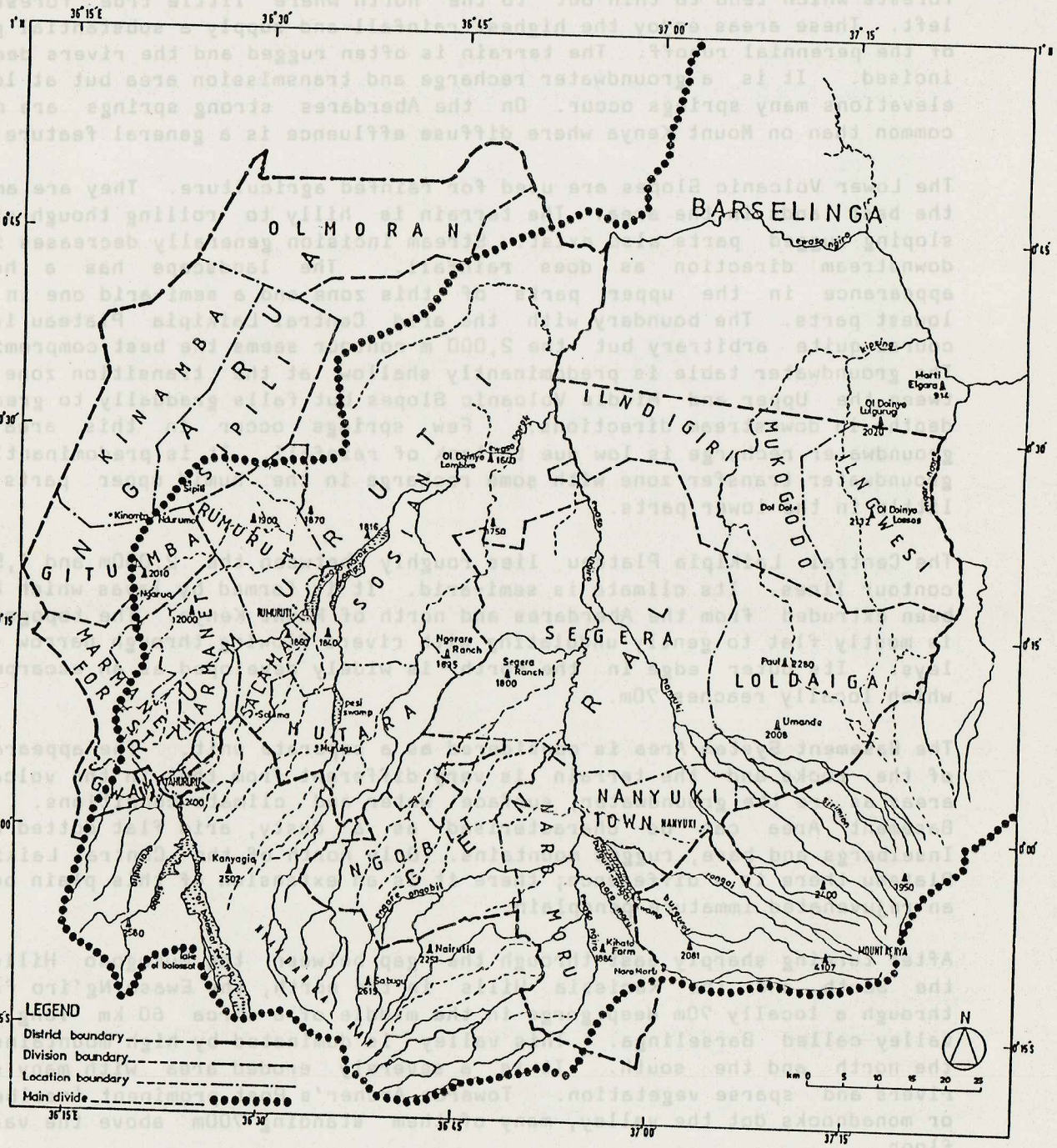


Figure 1.2 Location map

The western part of the District drains towards Lake Baringo. It is an intensively faulted and fractured area on the western edge of the Rift Valley. Climate varies from semi-humid to semi-arid. It includes the upper parts of the Wasseges and Mukutan catchments.

1.2.3 Drainage System

The Ewaso Ng'iro river system rises on the north-western slopes of Mount Kenya (5,199 m) and the north-eastern slopes of the Aberdares (3,999 m). Its dominant direction of flow is to the north. Its main tributaries are: Suguroi, Segera, Engare Ngobit, Karemena, Naromoro, Burguret and Rongai rivers.

The Nanyuki river which drains the north-western and northern slopes of Mount Kenya is the first major river to join the Ewaso Ng'iro. Tributaries of the Nanyuki river are the Liki, Ontulili, Kongoni, Sirimon, Teleswani and Timau rivers.

The Ewaso Narok is another major stream to join the Ewaso Ng'iro. It drains the northern end of the Aberdares range. Upstream of Thomson's Falls at Nyahururu its main tributaries are the Equator, the Oraimutia and the Simba rivers. Some discharge comes from the Ol Bolossat swamp system which is fed by numerous perennial springs. Below the Falls the main tributaries are the Pesi, Aiyam and Mutara rivers.

Downstream of the junction with the Ewaso Narok, the Ewaso Ng'iro flows in a predominant north-north-east direction, but after circa 25 km it swings sharply to the East into the arid areas of the Eastern Province to the Lorian swamp where the river disappears.

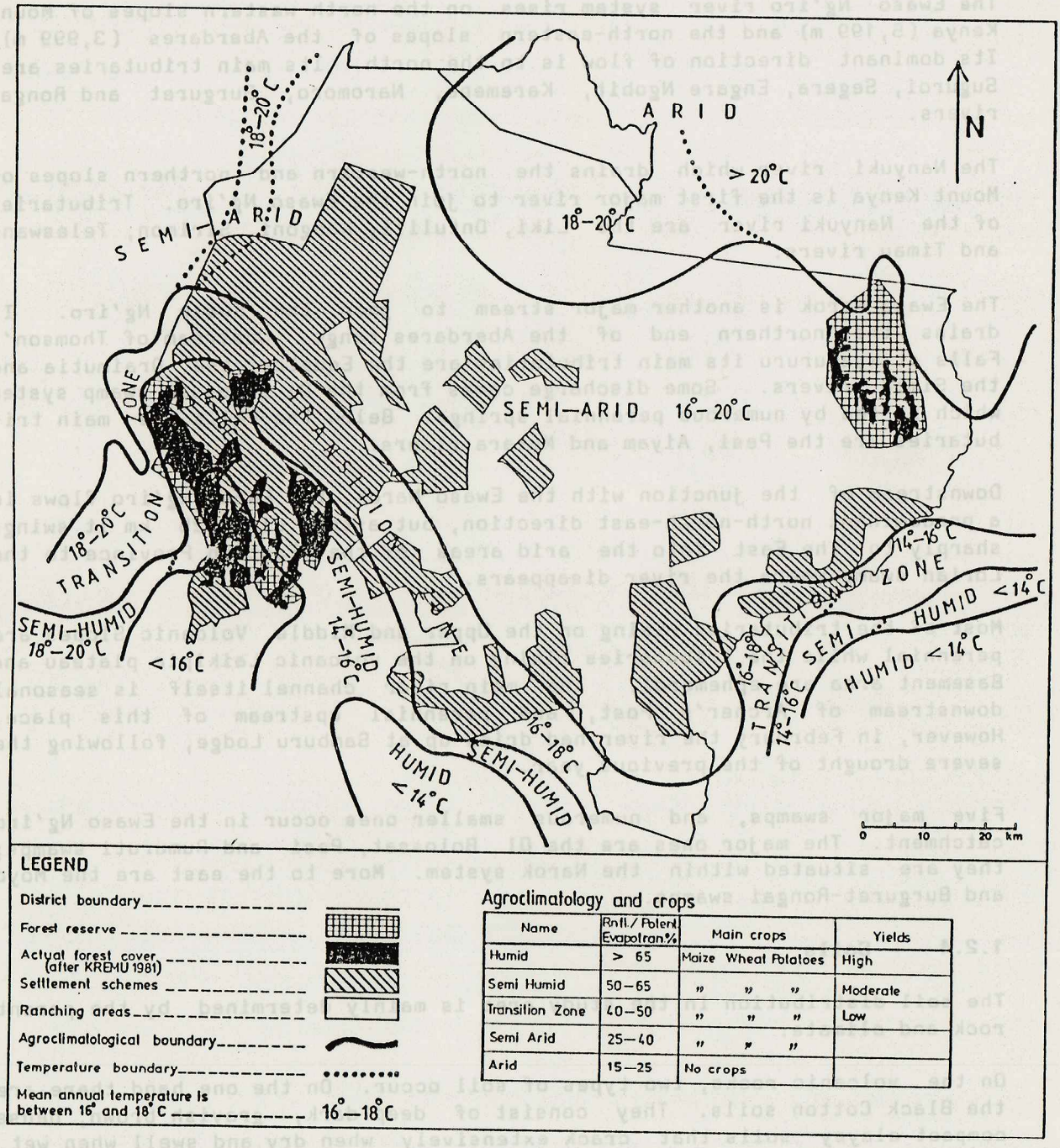
Most of the tributaries rising on the Upper and Middle Volcanic Slopes are perennial while the tributaries rising on the volcanic Laikipia plateau and Basement area are ephemeral. The main river channel itself is seasonal downstream of Archer's Post, and perennial upstream of this place. However, in February the river had dried up at Samburu Lodge, following the severe drought of the previous year.

Five major swamps, and numerous smaller ones occur in the Ewaso Ng'iro catchment. The major ones are the Ol Bolossat, Pesi and Rumuruti swamps; they are situated within the Narok system. More to the east are the Moyo and Burguret-Rongai swamps.

1.2.4 Soils

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

On the volcanic rocks, two types of soil occur. On the one hand there are the Black Cotton soils. They consist of deep dark, grayish brown, dense compact clayey soils that crack extensively when dry and swell when wet. They are moderately well drained, have a low permeability and are medium to high in natural fertility. The other type encompasses soils which are deep dark brown to reddish brown, well drained and have clayey loam to clay subsoils. They are medium to highly fertile and their infiltration capacity is moderate to low. Other soils on the volcanic plateaus and uplands are shallow and very shallow loamy and gravelly soils on low hills and on slopes along streams.



Agroclimatology and crops

Name	Rnfl./ Potent. Evapotran.%	Main crops	Yields
Humid	> 65	Maize Wheat Potatoes	High
Semi Humid	50–65	" " "	Moderate
Transition Zone	40–50	" " "	Low
Semi Arid	25–40	" " "	
Arid	15–25	No crops	

Figure 1.3 Landuse, Main Crops and Agro Climatic Zones

In the south-western part of the study area around Nyahuhuru, the soils have formed on volcanic rocks on footridges. They are deep reddish brown to red, clayey but very friable and porous. their infiltration capacity and permeability are high as is their natural fertility. They are among the most productive soils in the area.

Along the western edge and along some deeply incised streams in the southern part of the study area, mountains and major scarps occur consisting of phonolites and basalts. Soils in these areas are mostly shallow and very shallow consisting of gravelly clay loams and gravelly clays.

In the Basement System Area in the north-east of the study area, rocks consist mainly of banded gneisses and migmatites. A few outcrops of granite occur. There are two principal physiographic landforms: (i) rolling uplands and (ii) hills and minor scarps. Soils on the rolling upland are mostly moderately deep reddish brown friable sandy clay loams and sandy clays. Their permeability is moderate and natural fertility is medium though some areas have lost their natural fertility in the upper layer due to overgrazing and subsequent erosion. The soils on the hills and minor scarps are mostly moderately deep to shallow and very shallow sandy clay loams. Some are gravelly loams.

Five large and numerous small swamps are situated in the study area. They are characterised by poorly to very poorly drained, dark coloured, grayish loamy and clayey soils.

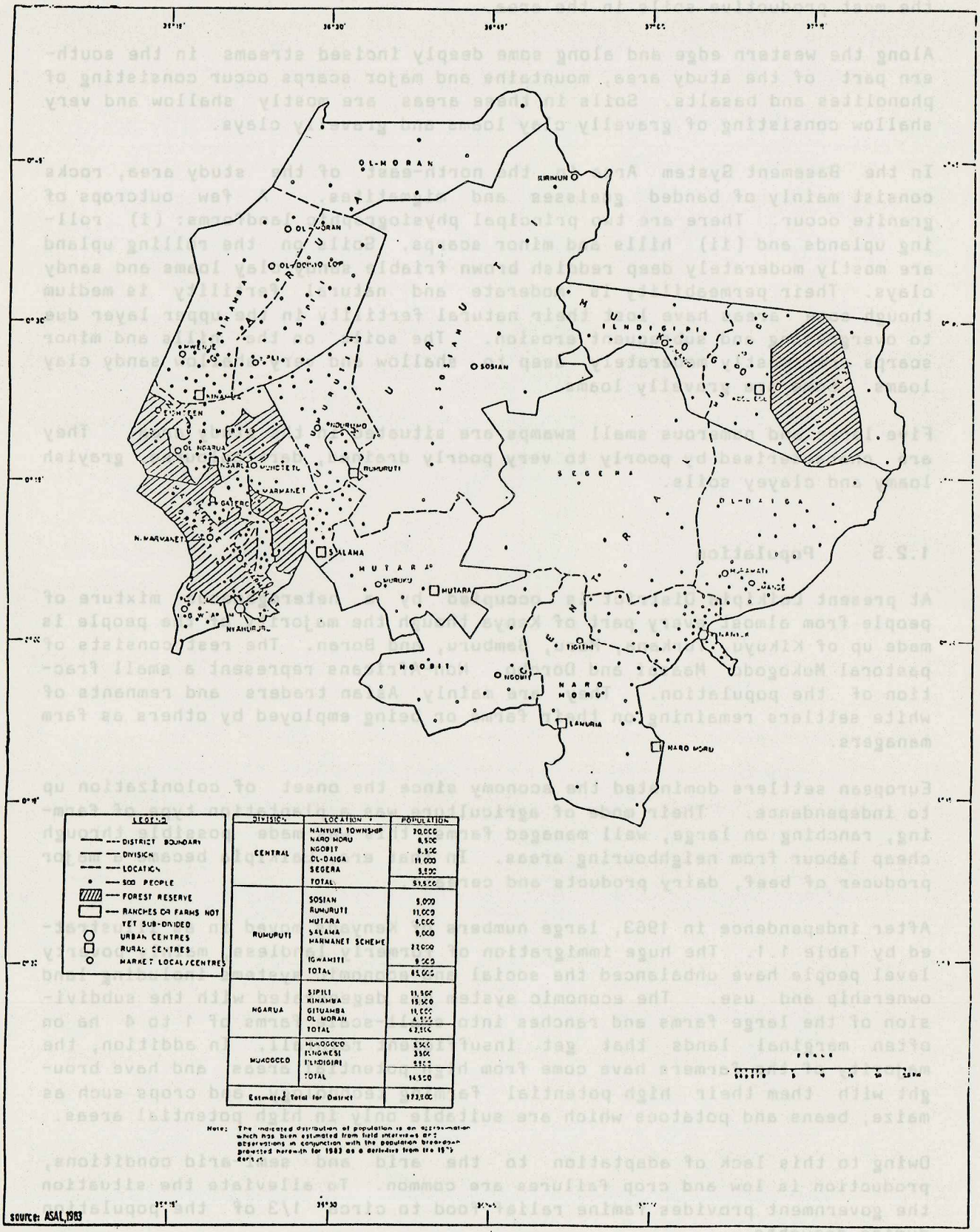
1.2.5 Population

At present Laikipia District is occupied by a heterogeneous mixture of people from almost every part of Kenya though the majority of the people is made up of Kikuyu, Turkana, Meru, Samburu, and Boran. The rest consists of pastoral Mukogodo Maasai and Dorobo. Non-Africans represent a small fraction of the population. They are mainly Asian traders and remnants of white settlers remaining on their farms or being employed by others as farm managers.

European settlers dominated the economy since the onset of colonization up to independence. Their mode of agriculture was a plantation type of farming, ranching on large, well managed farms; this was made possible through cheap labour from neighbouring areas. In that era, Laikipia became a major producer of beef, dairy products and cereals.

After independence in 1963, large numbers of Kenyans moved in as illustrated by Table 1.1. The huge immigration of formerly landless, mainly poverty level people have unbalanced the social and economic systems including land ownership and use. The economic system has degenerated with the subdivision of the large farms and ranches into small-scale farms of 1 to 4 ha on often marginal lands that get insufficient rainfall. In addition, the majority of the farmers have come from high potential areas and have brought with them their high potential farming technology and crops such as maize, beans and potatoes which are suitable only in high potential areas.

Owing to this lack of adaptation to the arid and semi-arid conditions, production is low and crop failures are common. To alleviate the situation the government provides famine relief food to circa 1/3 of the population during droughts.



DIVISION	LOCATION	POPULATION
CENTRAL	NANYUKI TOWNSHIP	20,000
	NARO MORU	8,500
	NGOBIT	8,500
	OL-DAIGA	11,000
	SEGERA	5,500
	TOTAL	51,500
RUMURUTI	SOSIAN	5,000
	RUMURUTI	11,000
	MUTARA	4,000
	SALAMA	9,000
	MARMANET SCHEME	22,000
	IGWAMITI	9,000
	TOTAL	85,000
NGARUA	SIPILI	11,500
	KINAMBA	15,500
	GITUAMBA	11,000
	OL MORAN	4,500
	TOTAL	42,500
MUKOGODO	MUKOGODO	5,500
	ENGWESI	3,500
	ENDIGIRI	500
	TOTAL	14,500
Estimated Total for District		193,500

Note: The indicated distribution of population is an approximation which has been estimated from field interviews and observations in conjunction with the population breakdown presented herewith for 1983 as a derivative from the 19?? census.

Figure 1.4 Population Distribution

Table 1.2 illustrates the population growth from 1932 until 1983. The high growth rate before 1946 was the result of migrant labour flocking into the district in search for employment on the white farms which by that time were being set up. The decrease in the period 1963 until 1969 is because many farms were being bought out leaving their labourers without work. The sharp rise since 1969 is a result of the mass immigration of Africans into the district to take up the vacated farms.

Table 1.1 Population 1923 - 1983 (Source, ASAL 1983)

Year	Europeans	Natives	Others	Total	Annual Increment
1923	166	1,481	184	1,831	
1929	290	6,621	30	6,941	25 %
1946	495	35,000	272	35,767	10 %
1962	691	68,643	699	70,033	4 %
1969	431	65,021	27	66,506	-1 %
1979	272	133,492	760	134,524	7 %
1983	not counted			173,428	(Extrapolated)

Figure 1.4 illustrates the distribution of the population within the district while Table 1.2 gives the details. It appears that the distribution is mainly related to the land availability: land was bought, subdivided and allocated to shareholders regardless of its potential.

Table 1.2 Population Projections 1979 - 1983

Division	1979	1983	1985	1988
Central	39,792	51,300	57,356	67,775
Rumuruti	48,279	62,241	69,589	82,231
Mukogodo	11,585	14,935	16,698	19,732
Ng'arua	34,868	44,952	50,258	59,388
Total	134,524	173,428	193,901	229,126

More than 1/3 of the population is concentrated in the high potential areas of Ng'arua and Marmanet. The rest is sparsely distributed in other parts of the district. Locations like Ng'obit, Naromoro and Segera in the Central Division are sparsely populated. Nevertheless, this could change drastically after all land buyers have settled as the average plot size in these areas is smaller (1 ha or more) compared to 2 1/2 ha or more in the high potential areas.

The annual intercensal population growth rate from 1969 to 1979 was 7.3% and the districts's population as per 1979 census was 134,524 (Table 1.2). The Central Bureau of Statistics estimates the Laikipia District's annual population growth rate from 1980 until 1988 at 5.55%. Using this estimate, the projected population on divisional level in the Laikipia district is shown in Table 6.3.

1.2.6 Livestock

The livestock in Laikipia District mainly consists of cattle, goats and sheep. The livestock data is presented in Table 1.3.

Table 1.3 Livestock in Laikipia

	1975	1976	1977	1978	1979	1980	1981	1982
Cattle	290000	340000	210000	220000	214400	220000	190000	160000
Sheep	101000	118000	130000	130000	128000	140000	122267	128381
Goats	11000	67200	810000	73000	85000	64000	76242	80000
Pigs	1500	1760	1500	1700	1663	1857	2500	2600
Donkeys	450	480	500	550	775	790	800	800
Camels	350	350	355	355	360	360	360	360
Poultry	15000	18000	16000	37000	44800	88750	116680	100000

2. GEOLOGY

2.1 Previous Studies

The first studies on the geology of Laikipia District were conducted by Prior (1903), Gregory (1919) and Campbell-Smith (1931). In the forties the systematic mapping of the district started. Shackleton (1945, 1946) mapped the central and southern part of the area. Some 20 years later the Mount Kenya area was studied by Baker (1967), while Mc Call (1967) finalised in the same year a study which included southwest Laikipia. Four years earlier in 1963, Bristow and Temperley published a useful study of the geology of central Laikipia with special reference to the groundwater conditions. Recently, a Kenyan-British team surveyed the greater part of Laikipia District.

The geological map of the study area (Plate 2.1) is based on the above mentioned geological studies. The whole district is covered by aerial photographs and Landsat images.

2.2 Geological Setting and History

Laikipia District lies on the eastern edge of the East African Rift Valley. It is wholly underlain by the Precambrian Basement System. It is bounded to the west by the Laikipia Escarpment and to the south-east and south-west by the volcanic edifices of the Aberdares and Mount Kenya. From these major eruption centres and a number of smaller ones, lava flows converged to the structural depression in the centre of the district.

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

The geological history of the area can be followed from the Precambrian era which is represented by the metamorphic 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 ever been deposited. As a result the Sub-Miocene or Early Tertiary peneplain originated. This is the erosion surface underlying the Tertiary and Quaternary volcanics. Remnants of it are found throughout Central Africa.

Subsequently a great series of lava sheets flooded out from the area which is at present the Rift Valley towards which the whole series thickens. These are the phonolites and plateau basalts whose eastern limit roughly coincides with the present Ewaso Ng'iro. According to Mc Call (1967) the main boundary faults of the Rift Valley originated after deposition of these lava flows.

After this, a prolonged period of relative stability started as evidenced by the remnants of an erosion surface in the Ewaso Ng'iro basin. This surface is known as the End-Tertiary peneplain. In general, it lies a few hundred feet below the afore described sub-Miocene level.

PERIOD	EPOCH	FORMATION			LITHOLOGY	maximum THICKNESS (metres)
QUATERNARY	RECENT	Alluvium			Loam,silt,clay,gravel	
	PLEISTOCENE	MOUNT KENYA VOLCANIC SERIES	Upper	(parasitic vents)	Basaltic pumice	60-100
			Middle	(parasitic fissure eruptions)	Trachytes, olivine basalts, mugearites, olivine trachytes	500
			Lower	(main eruptive episode)	Nepheline syenite of the plug Kenytes,phonolites,pyroclasts Phonolites and trachytes Porphyritic phonolites Unexposed volcanics	-- >600 >530 130 3000
TERTIARY	PLIOCENE	Ol Arabel Tuffs, Laikipian Basalts			Tuffs Olivine basalts	120 130
	MIOCENE	Sipili Trachytes Tasiokwank and Iguamiti phonolitic trachytes			Trachytes, Phonolitic trachytes	150 40
		Thomson's Falls Phonolites			Phonolites	85
		Rumuruti Forest Basalt			Basalts	-
		RUMURUTI GROUP	Upper Ewaso Narok Phonolites Marmanet Phonolites Lower Ewaso Narok Phonolites Ngelesha Phonolites		Phonolites	750
			Simbara Basalt Series		Basalts and agglomerates	>300
			Sub-Volcanic Sediments		Conglomerates	10
PRE-CAMBRIUM		Basement System			Gneisses, schists, quarzites	

Table 2.1 Simplified lithostratigraphic table of Laikipia District

In the following stage eruptive centres, mainly in the south, became active. Mount Kenya erupted and most of the other parts in the south, in particular the Aberdares, were covered with lava flows.

2.3 Stratigraphy

The stratigraphic description which follows is based on the geological reports No. 11 by Shackleton (1946), No. 12 by the same author (1945), No. 78 by Mc Call (1967) and No. 79 by Baker (1967).

The rock formations can be divided into three groups.

- Metamorphic rocks of the Basement System
- Tertiary volcanics
- Quaternary volcanics

The areal distribution of the rock formation in the study area is shown on Plate 2.1 and a summary of the lithostratigraphy is given in Table 2.1.

2.3.1 Basement System

The Precambrian Basement rocks are the oldest rocks in the area. They are believed to belong to the Mozambique orogenic belt of Eastern Africa. They comprise various types of sediments which were transformed by regional metamorphism into gneisses, schists and quartzites.

Basement System rocks outcrop in most of the north-eastern part of the study area (Plate 2.1)

The Basement System rocks were originally deposited as sediments and then subsequently altered by heat and pressure. In the study area, they consist mainly of gneisses with a broad banded structure and of migmatites and granites which are more homogeneous.

2.3.2 Tertiary Volcanics and Sediments

These deposits overlie the metamorphic rocks of the Basement System. Locally, underneath the phonolites, subvolcanic deposits of probably Lower Miocene age are found with a maximum thickness of about 10 metres, east of Kirimun. In the project area it outcrops approximately 5 kilometers north-east of Palagalagi - Ewaso Narok rivers confluence. These deposits, being the erosion products of the Basement System rocks, usually consist of well rounded pebbles.

The volcanic rocks in Laikipia District are products of eruptions which started in the Middle Miocene. The lower layers are basaltic while the upper ones are more phonolitic and trachytic. The lavas originated in many separate flows which are usually interbedded with tuffs and sediments.

Volcanicity in Laikipia began in the Middle Miocene with the extrusion of extensive series of plateau basalts (Simbara Basalt Series). Outcrops are locally found in the Laikipia Escarpment south of the Narok swamp and towards the confluence of the Mutara and Ewaso Ng'iro. The inferred eastern

limit of these lavas runs a few kilometers east of the Pesi and Narok swamps to the north.

During the Upper Miocene a phase of plateau phonolite eruptions followed. These phonolites cover most of the area west of the Ewaso Ng'iro. Their thickness decreases towards the east. The Aumuruti Group (comprising of Ngelesha, Lower Uaso Narok, Marmanet and upper Ewaso Narok Phonolites) and Thomsons Falls Phonolites are the most important members of this group. During the Miocene, the Laikipian Basalts erupted (Baker, 1967). These rocks lie unconformably on the plateau phonolites.

2.3.3 Quaternary Volcanics and Sediments

The main event during the Pleistocene was the origin of Mount kenya. Baker (1967) states that its volcanicity is probably Upper Pliocene but that the bulk of the volcanics is of Pleistocene age. However it must be realised that most of these volcanics are unexposed and that their nature is largely unknown.

The sequence of volcanic deposits is called the Mount Kenya suite. The Mount Kenya suite is divided into two parts: the volcanics of the main eruptive episode and the volcanics of the satellite vents. Rocks from the first episode are mainly basalts, phonolites and pyroclasts while those from the second period are mainly basalts, trachytes and agglomerates.

The most important representatives of the main volcanic episode are the porphyritic phonolites and agglomerates around Nanyuki while the basaltic lavas on the northern slopes of Mount Kenya are the most important representatives of the second episode.

2.4 Economic Geology

Valuable minerals have not yet been discovered. Even suitable building stone is rather scarce in most parts of the area. Trachytic tuffs deposits are being mined for building purposes near Timau and Nanyuki.

2.5 Structures

The position of the major faults obtained from existing geological maps, is indicated on Plate 2.1. In the Basement Area, the strike of the fold axes is predominantly north and north-west following the strike of the original sediments. Major faulting during the Precambrian has not been proved (Shackleton, 1946). During the Tertiary, two phases of faulting can be distinguished. The earlier was a grid-type faulting that produced the tilt block topography of the western part of the district whereas the later phase produced the enormous west-facing escarpments that form the eastern boundary of the Rift Valley.

The flatness of the Central Plain which is underlain by phonolitic lavas is probably due to an eastward tilt after their deposition. This has probably contributed to the origin of swamps along the rivers.

3. GEOPHYSICS

3.1 General

This chapter contains a summary of the geophysical investigations the Water Resources Assessment Project has carried out in Laikipia District. The investigations were done primarily with a view to selecting suitable drilling sites in a few areas of high water demand. An attempt to extrapolate the results in a regional sense is also made.

As mentioned in the chapter on geology and as will be seen later in the chapter on hydrogeology the district in general can be divided into two major geological units; the volcanic areas covering the central, southern and western sides and the Basement areas covering the eastern and north-eastern sides (the Mukogodo and Loldaika ridges).

In the volcanic areas regional aquifers were expected to exist, consisting of old land surfaces between the intermittent lava flows, contacts between various lavas and in the fault zones. The geophysical work was therefore planned with these facts in mind. Resistivity profiling (RP) and vertical electric soundings (VES, resistivity soundings) were the main methods applied here, although in two sites electromagnetic profiling (EM) was also tried.

In the Basement areas small poorly developed and difficult to contour aquifers were expected, mainly in the top weathered zones of the rocks (especially along the river valleys and in depressions) and in the fault zones. In most areas of the Basement, a series of north-south oriented anticlines and synclines whose flanks are composed of alternations of resistant rocks (gneisses and granitoid gneisses) and less resistant rocks (schists, marble etc) exist. These have their influence on the drainage pattern. Groundwater was expected to accumulate in the weathered zones of the less resistant rocks. In these areas the geophysical investigations had to be more thorough and more varied. EM, RP, VES and seismic spreads (in that order) were applied though not necessarily all the methods were tried per site.

Overall ten drilling sites were required in the district. The investigations were spread over 13 sites.

3.2 Previous Geophysical Work

Little geophysical activity is mentioned in any of the earlier technical reports of the district.

Some resistivity work seems to have been done by McCall in 1957. No details of the work are available although apparently it was on resistivity soundings. A conclusion drawn from the work carried out was that geophysics was not suitable for groundwater prospection in Central Laikipia.

Another work by Bristow and Temperley (1964) was done in 1962. This was comprised of EM and RP. The magnetic profiling was meant to locate con

Table 3.1 Completed Geophysical Fieldwork

Locality	Vertical Electric Soundings (VES)		Resistivity Profiling (RP)				Electromagnetic Profiling (EM)				Seismic Spreads (SS)			Shot Point Distance to nearest Geop (m)
	No of Soundings	Max AB/2 (m)	No of Profiles	AB/2 (m)	Station Intervals (m)	Total Length (m)	No of Profiles	Station Intervals (m)	Coil Separation (m)	Total Length (m)	No of Spreads	Geophone Spacing (m)	Total Length of spread (m)	
Ngomongo	5	490	2	50	15	2415	2	10	50	1260	-	-	-	
Bondeni	9	1000	4	50	15	2445	1	10	25	420	-	-	-	
Kandoro	3	630	2	50	15	1470	-	-	-	-	-	-	-	
Kanyingi	5	1000	2	50	20	900	-	-	-	-	-	-	-	
Mwenje	5	1000	2	50	20	5320	-	-	-	-	-	-	-	
Lariakorok	3	200	2	20,40,45	10	560	4	10	25	1430	2	7.5	165	3.75
Kopio	1	130	-	-	-	-	6	6.5, 10	46.5,50	1462	1	5	55	2.5
Kuri Kuri	2	400	-	-	-	-	1	10	50	240	-	-	-	
Dol Dol	1	250	-	-	-	-	1	10	50	360	-	-	-	
Osoit Oudo	1	160	-	-	-	-	5	10	25,50	2050	-	-	-	
Il Morupusi	2	400	1	45	10	400	6	10	50	1720	1	5	55	2.5
Tura/Ol Kimanjo	7	500	-	-	-	-	7	10	25,50	2080	4	5	220	2.5
Musul	1	400	-	-	-	-	1	10	50	630	1	5	55	2.5
Totals	45	-	15	-	-	13510	34	-	-	11652	9	-	550	

cealed faults in volcanic rocks. The results were reportedly successful except in tuff country where they failed even for faults whose existence were otherwise almost sure.

Currently the district has over 260 boreholes but apparently few of these were sited using geophysical methods.

Records in the Geology Section of the Ministry show about 55 vertical electric soundings to have been carried out since 1972. Of these, 32 were in the volcanic areas referred to above while 23 were in the Basement areas. The more recent ones were in the Schlumberger array while the earlier ones were in the Wenner array.

3.3 Geophysical Fieldwork and Results.

3.3.1 General

In all areas detailed background preparations preceded the actual field-work.

Aerial photographs, geological reports and topographic maps were studied to identify any features of interest such as lineaments, geological contacts, springs, drainage pattern and topography. In some cases photogeologic maps were drawn. Field checks were then made where other factors such as vegetation type and cover were noted (some species of trees such as the Acacia are known to do well where there is shallow groundwater). The most suitable geophysical methods were then decided upon depending on the identified features. Table 3.1 shows the details of the work done.

In the volcanic areas investigations were initiated with resistivity profiling. Where anomalies were picked up, soundings followed. At Ngomongo and Bondeni two EM profiles were tried mainly as an experiment on the applicability of the method to volcanic areas.

In the Basement areas EM preceded all other methods on account of its ease of execution and low cost. If any anomalies were picked up then they were followed up with RP, and if confirmed then further investigations were done with soundings and lastly (and rarely due to the high cost and being time consuming) with seismic spreads.

The detailed results of the geophysical site investigations are presented in Appendix 3:

- Discussions: 3.1
- Location maps: 3.2
- Sounding Curves Models and Geophysical Sections: 3.3
- Resistivity Profiles: 3.4
- Electromagnetic Profiles: 3.5
- Seismic Spreads: 3.6

3.3.2 Electromagnetic Profiling

A total of 11,652 m of profiling was executed distributed as shown in Table 3.1. In most cases at least two profiles were made parallel to one another and separated by a few hundred metres for comparison purposes.

The equipment used was the Maxmin II with 6 coil separation options (25, 50, 100, 150, 200 and 250m) and 5 frequency options (222, 444, 888, 1777 and 3555 HZ. In this fieldwork only the 25 m and 50m separations, and the 1,777 and 3,555 Hz frequencies were used as they were found (experimentally) to be the most applicable.

Both the In-phase and Quadriture-phase values were recorded per station and plotted in the field on ordinary graph paper. The stations were at 10m intervals for most profiles. Simultaneous double separation (25 m and 50 m) per station on the same profile was tried but it was found to be too cumbersome and time-consuming.

A description is given in Appendix 3.1 while the EM profiles are presented in Appendix 3.5.

3.3.3 Resistivity Profiling

Resistivity profiling was applied in the volcanic areas as an exploratory method while in the Basement areas it was a follow-up of electromagnetic profiling.

In the volcanic areas most lineaments were much more easily identifiable with the aerial photographs and therefore a single AB/2 reading per station on the resistivity profile was taken. Where the thickness of the weathered zones was doubtful, two AB/2 distances were applied on the same profile.

The equipment used was the ABEM SAS 300 Terrameter due to its portability. The AB/2 distances most commonly used were 50 m for the single reading profiles and 20 and 40 m for the double reading profiles. In all cases MN/2 was 5 m. Station intervals for the volcanic areas were 15-20 and in Basement areas 10m (to coincide with those of electromagnetic work).

In total about 13,510 m of resistivity profiling was done. Two of the longest profiles were 1,275 m and 4,480 m. Most of the others were much shorter; 200m to 750 m. Details are given in Table 3.1 and in Appendix 3.1, while the profiles are presented in Appendix 3.4.

In all cases the schlumberger array was used. The results were plotted in the field on double logarithmic graph papers similar to those used for soundings.

3.3.4 Vertical Electric Soundings

A total of 45 soundings were made. Of these, 25 were in the volcanic areas while 20 were in the Basement areas. Those in the volcanic areas were very long (maximum AB/2 = 1,000 m) and were made with the GEAS1 resistivity equipment generally. A few short ones were made with the ABEM SAS 300 Terrameter. The latter were only up to 500 m maximum AB/2 length. The great AB/2 length used in the volcanic areas was intended to probe as deep as possible (about 300-500m).

In the Basement areas, since only shallow aquifers were expected, much shorter AB/2 distances were used; none exceeded 500 m. They were made mainly with the ABEM SAS 300 Terrameter.

All the soundings were made in the schlumberger array although in a few cases the half-schlumberger array was used where there were difficult sites due to thick bushes or rocky ground. The MN/2 distances used were 0.5m, 5m and 10m.

A detailed description is presented in Appendix 3.1 while the sounding curves and models are presented in Appendix 3.3

3.3.5 Seismic Spreads

It has been mentioned above that seismic spreads were tried only in Basement areas, and even then only when all other methods were not very conclusive. This was due to the high cost of the method and the complicated pre-survey arrangements for explosives acquisition and security.

Generally only one spread per site was done. Most spreads had 5 m interval geophone spacings and the equipment used (EG & G Geometries ES 1210F seismograph) had 12 channels, i.e 55 m length of each spread. Two had 7.5m inter-geophone spacing.

A total of 9 spreads with a combined length of 550 m were made. Each had 5 shot points coded as Far Forward (FF), Forward (F), Centre (C), Reverse (R) and Far Reverse (FR). Shocks were in most cases generated with gelignite explosions but where convenient, a 5 kg sledge hammer was also used. The seismograph broke down during the tenth spread and consequently the spread could not be interpreted. Seismic profiling was not tried although at Lariakorok two adjoining spreads were made.

A description is given in Appendix 3.1 with the seismic spreads presented in Appendix 3.6.

3.3.6 Well - Logging

Since hitherto none of these sites have been drilled, no well-logging has been executed.

3.4 Geophysical Data Interpretation and Evaluation

3.4.1 Qualitative

The EM and RP data were evaluated only qualitatively. The main scope was to identify fault zones and weathered areas.

In the volcanic areas EM did not indicate the weathered areas or faulted zones as clearly as was hoped. The coil separation used was 50 m and frequencies of 1,777 and 3,555 Hz (these parameters had been experimented on Basement areas though). The intended depth of investigation was about 25 m.

In the Basement areas EM was more successful. Weathered areas were indicated although without such details as the layering pattern or the depth of weathering. In some areas such as at Dol Dol or at Il Morupusi

exceptionally strong anomalies were picked which were difficult to interpret. Details of these results are given in the site investigation descriptions in Appendix 3.1.

In the volcanic areas RP was more useful. Faults were more easily indicated. A good example is at Mwenje (Kinamba). This site is located almost at the edge of the Rift Valley and is very strongly faulted. Most of these faults are young and easily visible but a few of them are not so visible. Such faults were easily evidenced by the profiling. Another example is at Bondeni (Sipili) where the extension to the north of one of the many faults in the area was investigated using resistivity profiling.

A case where the method failed was at Ngomongo where a prominent lineament on the aerial photographs and which was believed to be a fault (as was also proved by soundings) was so not clearly shown by the profiling.

3.4.2 Quantitative

The soundings and the seismic spreads could be interpreted quantitatively. In some cases the results should be used with some reservations. The vertical electric soundings could identify the near-surface features such as shallow clay layers (e.g at Muruku or at Kanyingi) or shallow aquifers such as at Mwenje.

In the volcanic areas however with increasing depths of investigations, the problem of equivalent solutions becomes more serious, especially in this case where no drilling has been done to provide a counter-checking method. This has the effect of making VES of limited use in volcanic areas. Until drilling is done the interpretations have been kept as simplified as possible, maybe to be revised after drilling results are available.

In the Basement areas usually short soundings (200-500m) were made. Fewer lithological variations (both from site to site and also vertically within the same site) were expected. Therefore fewer problems with equivalent solution and simpler layer models could be made. Even then the interpretations had to be kept simple and the results will require updating after drilling is done.

Most sites in the Basement areas showed 3-4 layers with the first layer having about 1 m (or less) thickness and very variable resistivity (5 - 500 ohmmeters). Its resistivity depended mainly on the weather conditions (wet, dry) when the sounding was done and the type of soil (sandy, gravelly, clayey, marshy) of the particular site.

This thin top layer in most sites is underlain by a more clayey layer, with a less variable resistivity of 2.5 ohmmetres (where it contains brackish water e.g at Lariakorok) to about 23 ohmmetres at Tura. Its depth also varies between 2m to about 7.5m. Between this clay and the underlying fresh Basement in some areas a third less clayey layer was identified. This interpretation does not however imply laterally extensive layers, rather it implies a uniformity in the weathering pattern of these Basement rocks.

The seismic data was interpreted showing generally three shallow weathered layers, the topmost one consisting of the top soil, compacted to various degrees and with velocities ranging from about 300 m/sec at Musul to 800

m/sec at Lariakorok. Its thickness showed much variation ranging from about 1.7m at Il Morupusi to 9m at Lariakorok.

Below this topsoil a weathered layer with velocities ranging from about 1,000 m/sec to about 1,600 m/sec and depths to about 15m in some areas was identified. This was assumed to consist of clays and/or highly weathered Basement rocks. Finally, a third weakly weathered layer was identified with velocities ranging from about 2,000 m/sec to about 3,000 m/sec and depths ranging from about 17m to about 27 m (at Lariokorok) and may be much more at Ol Kimanjo. It probably overlays the fresh Basement which has velocities in the range of 5,000 m/sec.

In these four layers groundwater, if any, is expected to be in the second and third layer but the real situation will be known after the drilling is done.

Details are found in Appendix 3.1 to 3.6 respectively.

4. HYDROLOGY

4.1 Introduction

The hydrological studies are aimed at obtaining a basis for the estimation of the surface water potential of the project area.

The project covers an area of about 12,000 km² and is restricted to the upper catchment area of Ewaso Ng'iro basin, downstream to Ewaso Narok/Ng'iro confluence (Plate 4.1). This area is mainly Laikipia District (9,723 km²), and it has varied physiographic and climatic features. Mountainous areas are found to the south (Nyandarua ranges and Mount Kenya) while the central and northern areas are mainly a plateau.

The climate of this area is heavily dependent on altitude with low-lying areas experiencing a hot and dry climate while the mountainous regions enjoy a cool and temperate climate.

The area is drained by two important rivers systems: the Ewaso Narok to the west and Ewaso Ng'iro to the east. Ewaso Narok has its source in the Nyandarua Mountain Ranges while Ewaso Ng'iro rises from both Mount Kenya (major source) and Nyandarua ranges. After their confluence, the river is named Ewaso Ng'iro and flows through an arid area disappearing in its sandy river bed before entering Lorian swamp some 500 km downstream of the confluence.

4.2 Previous Hydrological Studies

A number of previous studies on Ewaso Ng'iro river have been carried out since 1940 but the most important study in terms of detailed work is the report by Ministry of Works, Hydraulic Branch, entitled "An Investigation into the Water Resources of the Ewaso Ng'iro Basin Kenya", 1958-61. This is a very comprehensive report on all aspects of water resources availability and development covering the whole basin. Hydrologic analyses of rainfall and runoff data such as reliability and frequency studies were carried out using the available data. At that time most of the records however were fairly short especially those of runoff. The report recognised the limited surface water resources potential to develop agriculture in the upper catchment area and recommended more use of groundwater resources where available. Possible dam sites were investigated to store flood water for use during the dry season. Reclamation of the swamps in the upper catchment for agricultural development was also investigated and recommendations were made.

The WHO 1973 report contains hydrologic analyses of tables of mean monthly and annual discharges of 26 river gauging stations (RGSs), frequency distributions of mean monthly discharges for nine RGSs and flow duration analysis for 26 RGSs in Ewaso Ng'iro basin. They also published river basin runoff characteristics and maps of:

- low flow run off, 95% flow duration in 1/s per km²
- mean annual run off in 1/s per km²
- low flow discharge, 95% flow duration in m³/s

- mean annual discharge in m^3/s
- mean annual rainfall etc.

It should be noted however that the figures in of this report are on the high side and should therefore be cross-checked before use.

The 1983 ASAL report on Laikipia District discusses in some detail the climate of the district and relates it to agricultural production. In Vol.IV of this report conservation of soil and water is discussed. In addition, the report recognises the limited surface water resources in which all low-flow supplies have been utilized. Water conservation by construction of small and large dams is foreseen in addition to drainage and irrigation of the large swamps.

A number of papers and reports on the hydrology of the north-western part of Mount Kenya (ca 600 km^2) were prepared by scientists of the University of Bern. The most important ones follow. Leibundgut (1983) analysed monthly means streamflow of 12 RGSs for the period 1960-1980. From the same author, a Hydrogeographical Map of Mount Kenya appeared in 1986. Decurtins (1985) analysed water balances of various subzones of the Naro Moro catchment.

4.3 Hydrometeorological Network

The southern part of the study area is fairly well covered by a hydrometeorological network, compared to the northern and eastern areas (Plate 4.1). There are five meteorological stations in the project area and three outside the area. The Ol Joro Orok station is a complete agrometeorological station while others have at least the basic meteorological equipment such as maximum and minimum thermometers, anemometers, etc.

4.3.1 Rainfall Network

Most of the rain gauges are located in the densely populated areas in the south. They are sparsely distributed in ranches and nomadic areas in the central and northern parts (Plate 4.1).

Rainfall data are kept by Kenya Meteorological Department (KMD) and to a lesser extent by the Hydrology Section of the Ministry of Water Development (MOWD). However, exchange of data takes place between the two institutions.

Inside the project area, the oldest rainfall station is found at Rumuruti D.O which started operating in 1906. Rain gauges at Sipili and Ol Morani were installed by the WRAP project in May/June 1985 with the aim of expanding the network in the eastern part.

Rainfall station details and available records in some of these stations are shown in Appendix 4.1. Discontinuities in the records are mainly due to negligence of rain gauges by the observers.

4.3.2 Evaporation Network

There are twelve evaporation pans in the study area, eleven of which are Class A pans and one Class B pan. Five of these Class A pans were installed by the WRAP project in May/June 1985. Records of evaporation data go back to 1946 at Nanyuki and Ol Joro Orok meteorological stations.

Outside the project area, evaporation pans are found at Archer's Post, Isiolo, Meru and Nyeri. The network for evaporation pans with the installation of the five new ones can be considered adequate (Plate 4.1)

Evaporation data are collected and stored by the same agencies dealing with rainfall data i.e. KMD and MOWD. Other meteorological data on wind, sunshine, radiation etc can also be found in the same institutions.

Evaporation station details are compiled in Appendix 4.2.

4.3.3 River Gauging Stations (RGSs)

There are 42 open and 35 closed RGSs on Ewaso Ng'iro/Narok river systems upstream of their confluence. Most of these stations have staff gauges and weirs installed and are mainly found on the tributaries feeding the main river systems, mostly from Mount Kenya area. There are 19 existing water level recorders in the basin, 11 of which have been installed by ASAL in the tributaries originating from Mount Kenya on the Naro Moru - Timau tarmac road, 4 solid state recorders have been installed by WRAP and the rest by MOWD.

WRAP rehabilitated the pneumatic water level recorder at Archer's Post and good high water level readings were obtained during the rainy season of April/May 1986. The importance of this station cannot be overemphasized as it monitors the combined flows of Ewaso Ng'iro/Narok systems in the middle catchment area of Ewaso Ng'iro basin. It is about 130 km downstream of the confluence.

The location of the various RGSs is shown in Plate 4.1, station details and the available records are summarized in Appendix 4.3.

All runoff data are kept by the MOWD Hydrology Section. Runoff records data go back to 1931 on five tributaries of Ewaso Ng'iro system from Mount. Kenya. On Ewaso Narok system, the oldest records are from 1945.

Due to lack of flood gauging equipments, e.g. cable ways and winches, peak flows have not been monitored and consequently the reliability of the rating curves at high water levels is poor.

4.3.4 Monitoring of Surface Water Quality

- **Chemical Quality**

A regular sampling network for water chemical analysis has not yet been established by the MOWD. Sampling is usually done at irregular time intervals when someone from the Ministry's Water Quality and Pollution Control Division happens to visit the area or when a request is made to investigate the quality of a certain source.

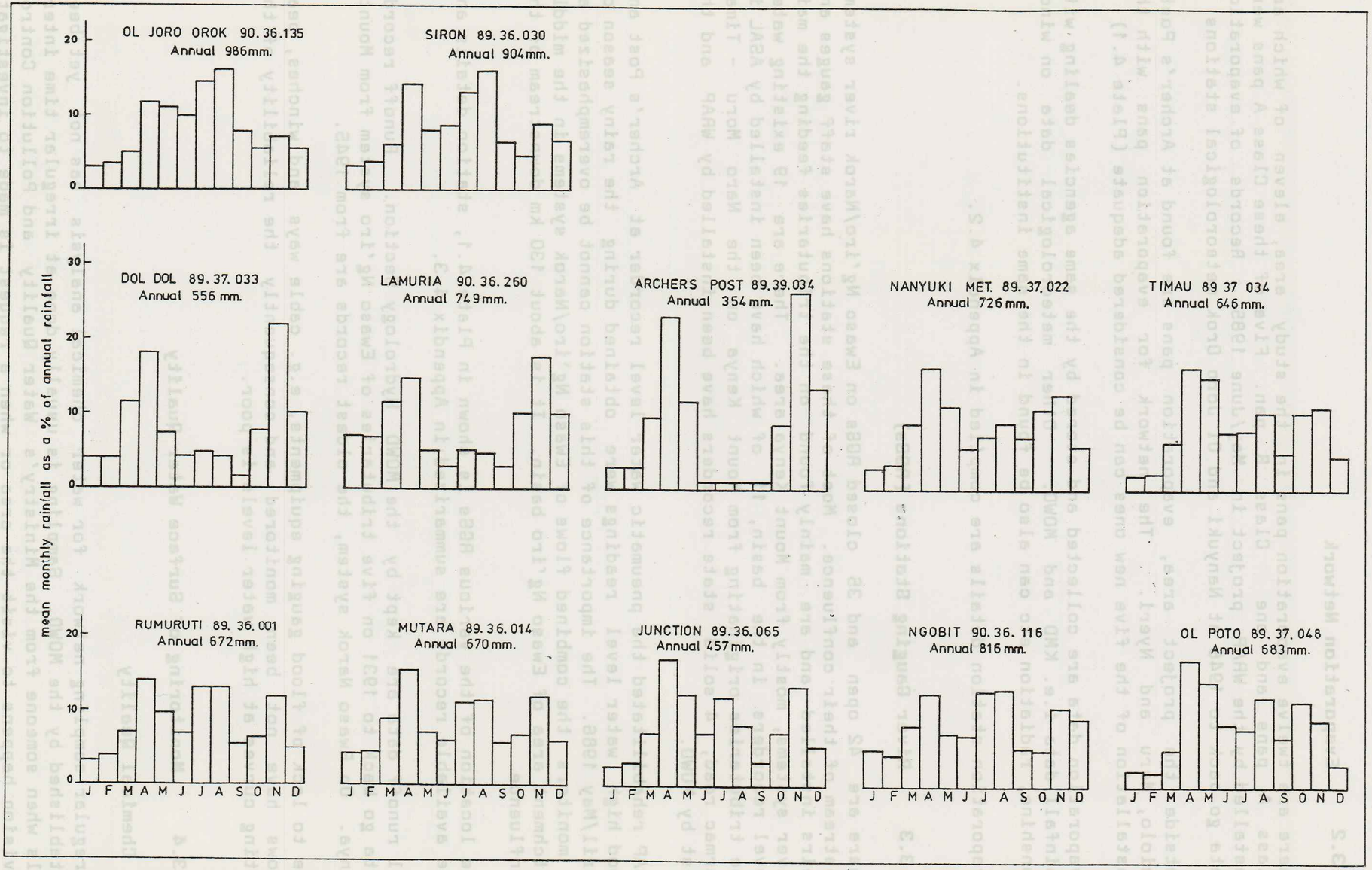


Fig 4.1 Mean monthly rainfall distribution patterns

26

WRAP has set up a regular programme for the monitoring of the surface water chemical quality covering most rivers and streams. Sampling was done at each RGS and other suitable sites during discharge measurements.

- **Suspended Sediment**

Some sediment sampling has been carried out by the Hydrology Section between 1979 - 1982. The number of samples collected at each RGS ranged from one at 5D5 to 10 at 5BE6.

Previous records indicate that a sampling campaign covering twelve RGSs was also in existence between 1949 - 65 when as many as 574 suspended samples were taken at Archer's Post 5E3. A lower number of samples, 64, 63, 65 and 65 respectively, were taken at 5BE2, 5BE4, 5BE5 and 5BE6 as indicated in Table 4.1.

WRAP did not carry out a suspended sediment sampling campaign as its study does not include morphological analysis of the rivers.

Table 4.1 Suspended Sediment Sampling

RGS	River	No. of samples collected between 1949 - 65	1979 - 82
5AA1	Ewaso Narok		3
14	Oraimutia		1
5AB 3	Pesi		2
5AC 2	Narok channel		4
4	Narok channel		1
8	Ewaso Narok		3
5AD	Mutara (Misc)		1
5BB 2	Ewaso Ng'iro	358	6
5	Karemeno		2
5BC 2	Naromoru	117	
5	Rongai	107	
6	Burguret	117	
8	Engare Ngobit	372	7
5BE 1	Nanyuki	156	
2	Ontulili	64	
4	Sirimon	63	
5	Teleswani	65	
6	Timau	65	10
7	Liki		5
12	Liki (south)		3
21	Nanyuki		3
5D 5	Ewaso Ng'iro	150	1
5E 3	Ewaso Ng'iro	574	4

4.4 Rainfall Distribution

Generally speaking, low lying areas receive less rainfall than the highland areas due to the orographic nature of the rainfall. In Laikipia District,

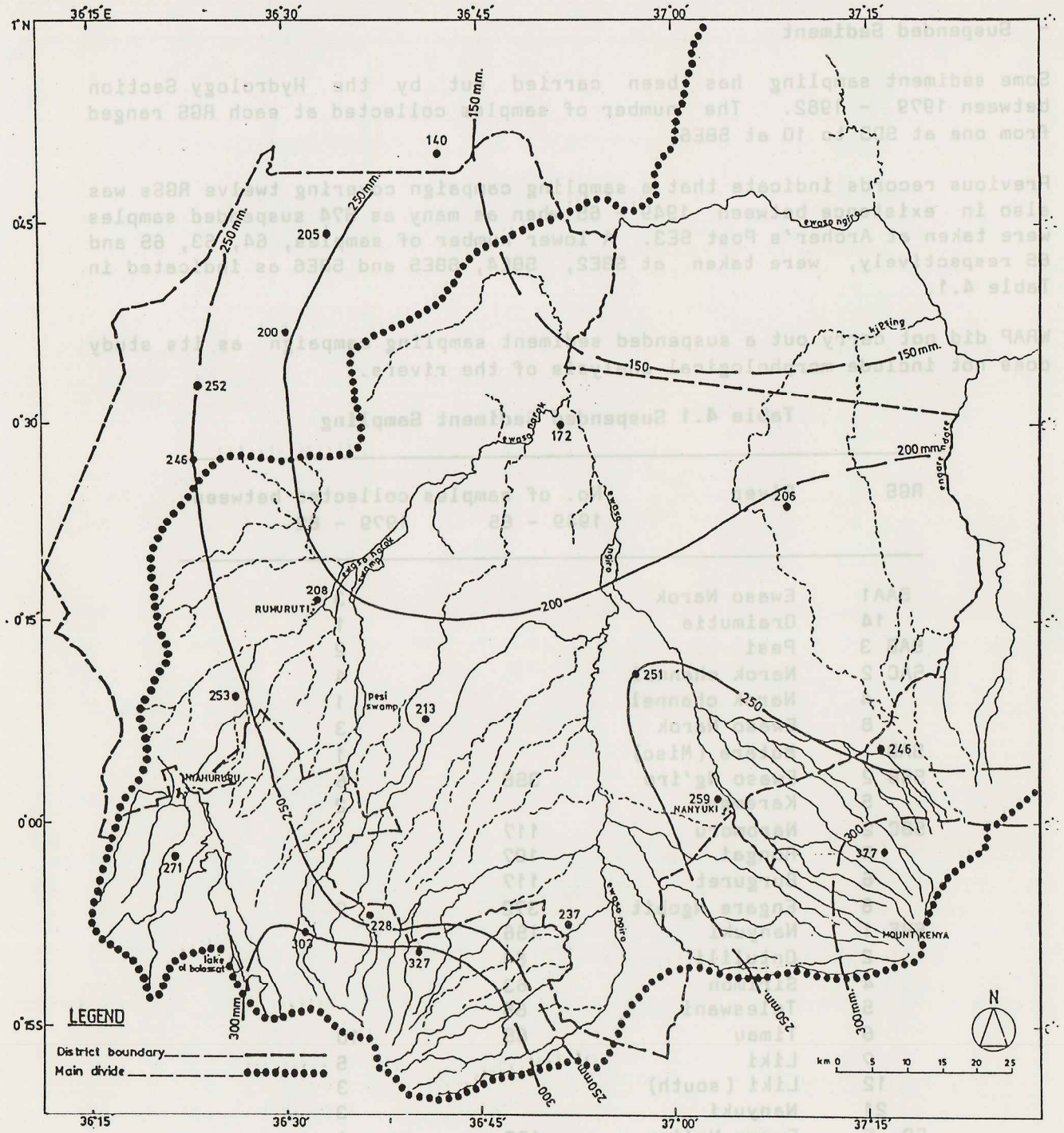


Figure 4.2 Mean Seasonal Rainfall - Long Rains (March-May)

this trend is observed in the mountainous area to the south and south west of the district which receive over 800 mm of annual rainfall as compared to the low lying semi-arid area to the north which gets about 450 mm.

To study rainfall patterns in the district, twelve rainfall stations with good records and site characteristics have been selected for detailed analysis to indicate rainfall distribution in the area and its variations in time. Archer's Post rainfall station has been included although it is located in the middle catchment area to indicate rainfall conditions there.

4.4.1 Monthly Rainfall

Rainfall distribution in both time and space is given in Table 4.2. The highland areas to the south and southwest receive good rainfall amounts in the months of April-August as indicated by rainfall stations at Siron Farm and Ol Joro Orok. Outside this rainy season the rain continues. Only the months of January and February get very low rainfall amounts and thus, rainfed agriculture does very well here.

On the slopes of Mount Kenya a two peak rainfall pattern is exhibited in April/May and October/November (Nanyuki). The Mount Kenya area, like the Nyahururu area, gets well distributed monthly rainfall which maintains a thick forest cover and feeds the aquifers from which the springs and hence the river systems originate.

The Laikipia Plateau which covers most of the central area experiences a less well distributed rainfall but good enough to maintain ranches. The Rumuruti area exhibits a three peak rainfall pattern in April/May, July/August and October/November, while the Ardencaple farm station at Timau exhibits basically two peaks and a weak third peak in August.

The semi-arid north and northeast gets poorly distributed rainfall, capable of maintaining poor vegetation cover. Dol Dol and Archer's Post exhibit a two-peak rainfall pattern.

The rainfall patterns discussed above are exhibited in Figure 4.1

4.4.2 Seasonal Rainfall

In general, over 85% of annual rainfall falls in two or three rainfall seasons. These are:

(a)	Long rains	March-May
(b)	Continental rains	June-August
(c)	Short rains	October-December

The long rains are associated with the south-east monsoons and provide the best rainfall distribution in the upper basin. Nearly the whole of Laikipia District receives more than 200 mm of rainfall during the long rains except the Junction area which receives about 170 mm (Figure 4.2)

The continental rains resulting from convective activity over the land are confined to the western edge of the basin - Nyahururu-Ng'arua area as the moisture bearing winds originate from the Congo basin and Lake Victoria to the west. The north-eastern part of the district receives less than 150 mm and Naro Moru and Dol Dol areas receive even less than 100 mm (Figure 4.3).

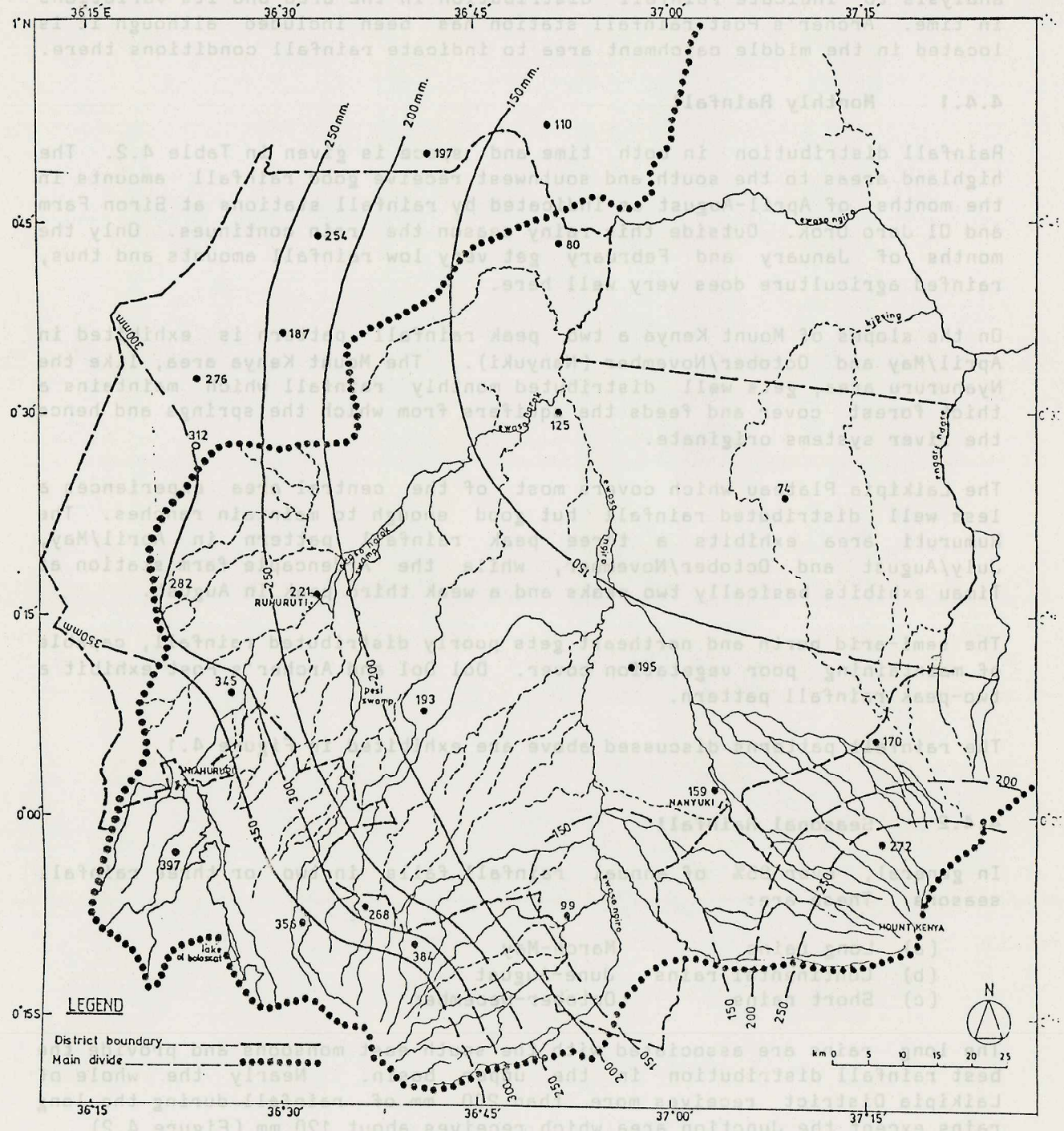


Figure 4.3 Mean Seasonal Rainfall - Continental Rains (June-August)

The short rains arrive with the north east monsoons and are fairly well distributed over the southern part of the basin (Nyandarua mountain ranges and Mount Kenya areas) with amounts of over 200 mm. The north western area covering mainly Rumuruti and Ng'arua Divisions receive less than 150 mm. Ngarua division is even drier than Rumuruti and receives less than 100 mm (Figure 4.4).

Table 4.2 Mean Monthly Rainfall Distribution (mm)

Rainfall Station	Period of Record	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Annual
Rumuruti D.O 89.36.001	1906-85 No data 1913-17	22	26	48	95	65	47	87	87	37	43	79	33	672
Mutara Estate 89.36.014	1936-85	28	30	60	104	49	41	75	77	39	46	80	41	670
Siron Farm 89.36.030	1935-81 No data 1967-72	29	33	54	128	71	79	120	146	59	43	81	60	904
Junction 89.36.065	1949-85 No data 1954-7	12	14	33	78	61	33	54	38	15	33	61	24	457
Nanyuki Met 89.37.022	1939-85	20	25	57	119	83	41	53	65	50	78	92	42	726
Dol Dol 89.37.033	1948-85	22	21	64	101	41	24	26	24	9	43	123	57	556
Timau - Ardencaple 89.37.034	1948-85 No data 1955-6	13	14	41	107	98	50	52	68	33	68	73	29	646
Archer's Post 89.37.035	1946-85	10	10	34	82	42	2	4	3	3	31	94	40	354
Nanyuki - Olpoto farm 89.37.048	1950-85	15	14	37	118	96	58	54	83	46	79	61	21	683
Ngobit, Deighton Downs 90.36.116	1927-79	40	36	68	102	58	56	104	108	44	40	87	74	816
Ol Joro Orok Met 90.36.135	1946-85	31	33	48	114	109	97	141	159	76	54	68	54	986
Lamuria 90.36.260	1959-85	54	52	86	111	40	23	39	37	24	76	133	75	749

Table 4.3 shows how mean annual rainfall is distributed over seasons as discussed above. It is evident that just over 85% of annual rainfall falls during the three rainy seasons (e.g Rumuruti) or two rainy seasons (Archer's Post).

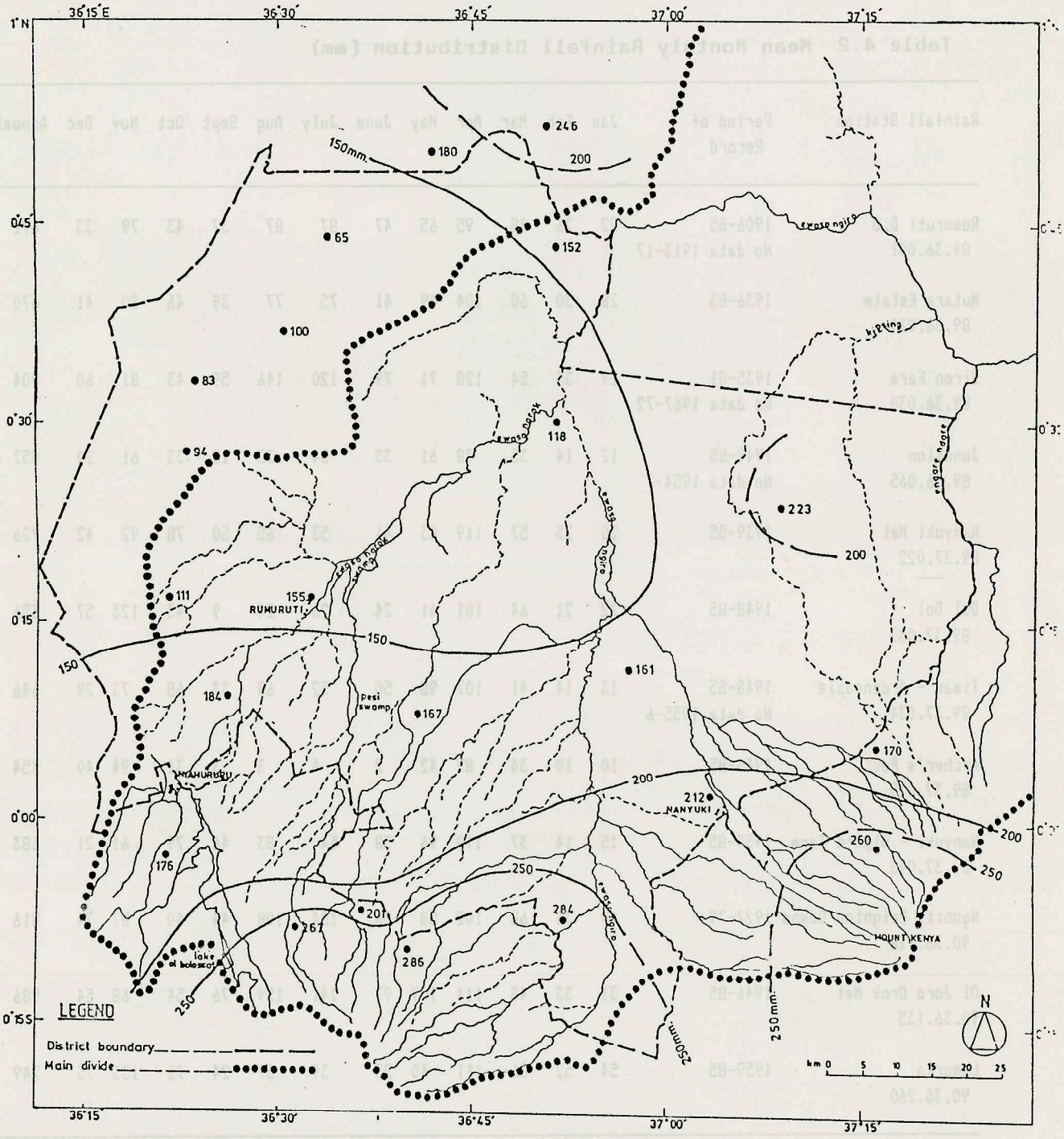


Figure 4.4 Mean Seasonal Rainfall - Short Rains (October-December)

Table 4.3 Mean Seasonal Rainfall Distribution in Percent (%)

Station	Long Rains March-May	Continental Rains June-Aug.	Short Rains Oct-Dec	Others
Rumuruti 89.36.001	31	33	23	13
Mutara 89.36.014	32	29	25	14
Siron Farm 89.36.030	28	38	20	14
Junction 89.36.065	38	27	26	9
Nanyuki 89.37.022	36	22	29	13
Dol Dol 89.37.033	37	13	40	10
Timau 89.37.034	38	26	26	10
Archer's Post 89.37.035	45	3	47	5
Ol Poto Farm 89.37.048	37	28	24	11
Deighton Downs 90.36.116	28	33	25	14
Ol Joro Orok 90.36.135	27	40	18	15
Lamuria 90.36.260	32	13	38	17

4.4.3 Annual Rainfall

The distribution of annual rainfall closely follows the monthly distribution. The southern areas which include Nyahururu, Nyandarua ranges and Mount Kenya are endowed with heavy annual rainfall amounts of over 800 mm. The Nyahururu area is the wettest (over 1,000 mm).

The central plateau which covers most of the Laikipia District area gets rainfall in the range 600-800 mm per annum while the semi-arid north receives between 400-500 mm.

Areal distribution of annual rainfall is shown in the isohyetal map, Plate 4.1. This map is based on all rainfall data available up to 1985.

From the isohyetal map, it is evident that most of Laikipia District receives less rainfall than neighbouring Meru and Nyeri districts. This is due to the masking effect of the Mount Kenya and Nyandarua Mountain Ranges to the moisture bearing winds of South-East monsoons. This sheltering effect places Laikipia District in the leeward side of the two barriers, while the other two districts are on the windward side and receive most of the rainfall from the monsoons.

4.4.4 Trend of Annual Rainfall

Five rainfall stations were used to determine the trend of annual rainfall. These are Rumuruti 89.36.001, Marania 89.37.002, Sirimon 89.37.043, Deighton Downs 90.36.116 and Ol Joro Orok 90.36.135. Rumuruti has the longest record starting in 1906 but only 1918-85 record was used due to lack of 1913-17 data.

The annual rainfall data were fitted with a 5-year moving average and the resultant trend lines show that annual rainfall was below average between the early thirties and early fifties with drought conditions occurring in the early forties.

Rumuruti shows the early seventies and early eighties as periods of rainfall below average while Marania has the period early sixties to seventies as having below average rainfall. The early eighties was not a dry period in Marania area as rainfall was above average (Appendix 4.4).

4.4.5 Maximum Daily Rainfall

Maximum daily rainfalls are important in hydrology as they tend to cause flooding during the rainy seasons. These data can also be used to forecast the occurrence of a flood and hence precautionary measures taken in time to avoid losses of lives and property. A study of maximum daily rainfalls occurring in each year will give an indication of areas likely to be subjected to severe flash flooding during the rains.

Table 4.4 summarises the maximum daily rainfalls which are likely to be reached with return periods of 100 and 50 years (also Appendix 4.4).
It will be noted that big storms are generally rare in upper Ewaso Ng'iro basin. However one station on the slopes of Nyandarua Mount Ranges, Ngobit farm (90.36.117) at an altitude of 2,440 m shows significantly high maximum daily rainfalls, which appear to be caused by the local physiographic features as neighbouring stations do not show similar high values of maximum daily rainfall. Such storms are likely to cause severe flooding in the area. The Nyahururu area also indicates higher maximum daily rainfalls than the other areas in the upper basin.

In the middle catchment area, Wamba and Archer's Post rainfall stations do indicate high maximum daily rainfalls which may partly explain the existence of severe flash floods in this area. Rainfall in this semi-arid area is known to be very intense and falling mainly on bare soil and rock.

Table 4.4 Frequency Analysis of Maximum Daily Rainfall (probability of maximum daily fall (mm) reaching values shown in a year)

Station		Probability		Length of Record Used
Name	Number	100yr. (1%)	50yr. (2%)	
Rumuruti D.O	89.36.001	133	121	48*
Thomson's Fall marmanet	89.36.002	163	145	34
Nanyuki, Avontuur	89.36.003	107	94	25
Laikipia Forest Station	89.36.005	117	104	10
Rumuruti, Mutara Estate	89.36.013	89	81	33
Leshau Pondo Health Centre	89.36.027	145	130	17
Junction	89.36.065	100	93	16*
Timau, Marania	89.37.002	135	122	17
Timau, Ardencaple	89.37.011	81	74	17
Maralal, Wamba	89.37.018	190	170	26*
Nanyuki met station	89.37.022	99	89	43*
Timau settlement scheme	89.37.030	124	112	14
Dol Dol D.O Office	89.37.033	106	97	29*
Archer's Post Met Station	89.37.035	147	130	36*
Subukia, Ol Momoi	90.36.000	109	99	37
Naro Moru, Kenya Park	90.36.014	107	84	26
Ol Kalou Railway Station	90.36.055	84	76	24
Karemeno Estate	90.36.085	104	97	22
Ngobit, Suguroi Estate	90.36.099	109	99	23
Ngobit Farm	90.36.117	208	183	13
Ol Joro Orok Agromet Station	90.36.135	112	102	14
Naro Moru, Ol Tarakwai	90.37.023	96	89	19
Kangaita Forest Station	90.37.060	84	76	35*

Source: 1962 MoW - Hydraulic Branch Report No. 4

* Computed values (see Appendix 4.4)

4.4.6 Filling Missing Data

Gaps in rainfall records have been filled using various methods.

Monthly rainfall totals have been filled by averaging five previous and five subsequent monthly totals of the same month.

Annual rainfall totals have been filled using linear regression analysis with neighbouring stations. e.g to fill Rumuruti (89.36.001) 1951-3, and 1959 data, a regression equation with Mutara (89.36.014) was obtained as

$$\text{Rumuruti} = 1.05\,(\text{Mutara}) - 4.82$$
$$r = 0.83$$
$$n = 16$$

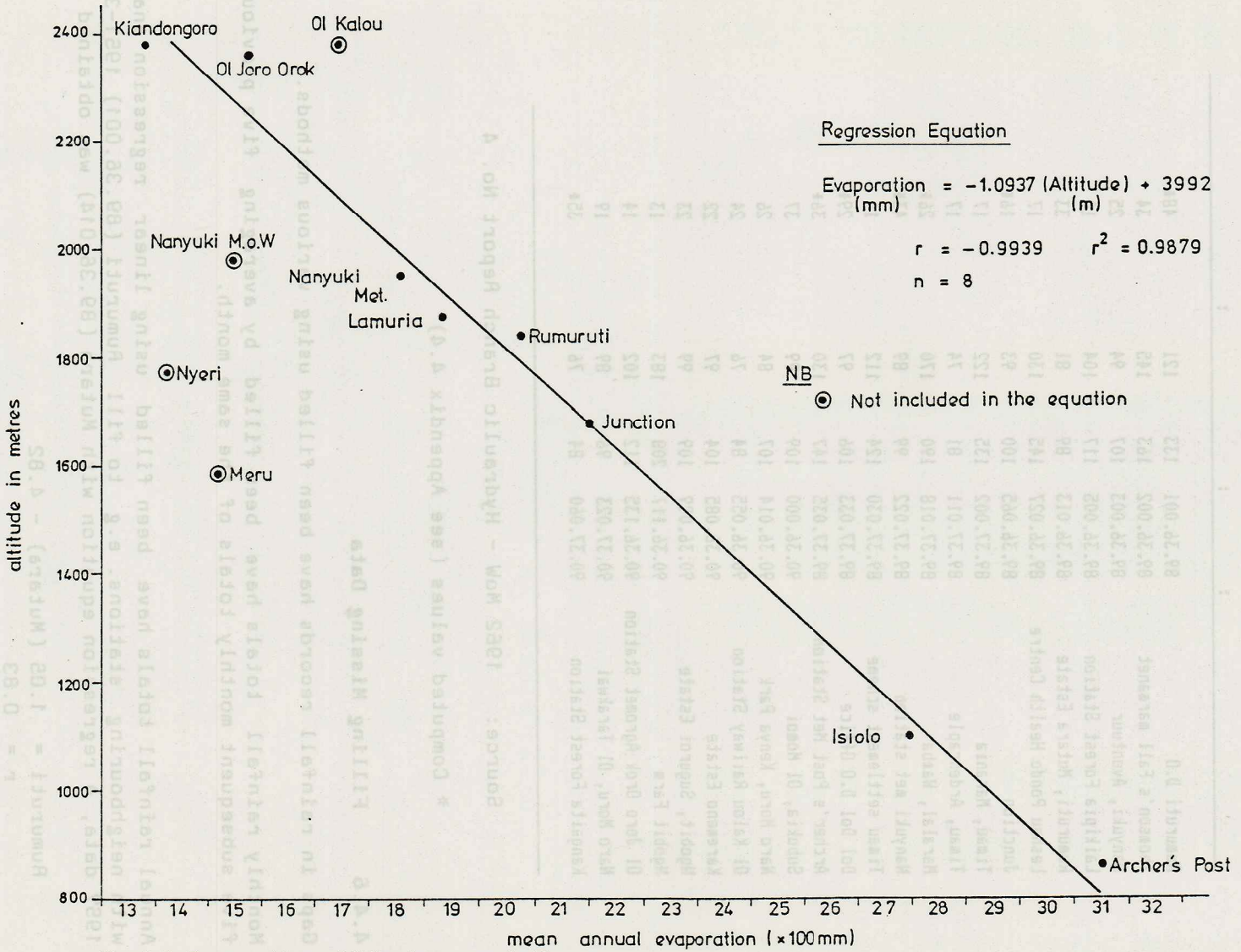


Fig. 4.5 Evaporation - Altitude correlation

And to fill Rumuruti (89.36.001) 1978, 1983-5 data, the ratios method using the mean annual rainfalls of stations 89.36.001 and 89.36.064 were used.

4.5 Evaporation

Estimates of evaporation rates from open water surfaces are essential in studies of crop water requirements, catchment area research and management and in the design of reservoirs for irrigation and hydropower generation. The class A pan of the U.S. Weather Bureau is most widely used to estimate the water demand of the atmosphere.

Due to its make and installation, the pan estimate of evaporation rates is higher than are calculated from meterological data and a pan coefficient of between 0.6 - 0.8 is applied to get a better estimate of potential evapotranspiration rates.

Annual evaporation rates are known to be a function of the altitude of an area and the low lying northern areas of Laikipia District experience high evaporation rates of over 2,000 mm (Junction) while the highlands to the south are cool and lose about 1,500 mm (Ol Joro Orok). Figure 4.5 shows a very high negative correlation of evaporation versus altitude for the Ewaso Ng'iro Basin. It is shown that evaporation data collected at Nyeri and Meru do not fit the line probably due to the cool weather prevailing at those particular sites of low altitude. The departure from the line for Nanyuki MoW and Ol Kalou could be due to operational errors.

Table 4.5 gives the mean monthly evaporation rates of the basin estimated by the class A pan while Figure 4.6 shows their monthly variations. In all the stations high evaporation rates occur during the months of Jan-March, with a peak mostly in March when the rainfall is very low. The months of peak rainfall at each station coincide with the months with lowest evaporation due to the cloudy atmosphere and low temperatures prevailing by then (Appendix 4.5).

Woodhead (1968) estimated potential evaporation (Eo) rates in Kenya and Table 4.6 compares his results with class A pan estimates for four stations in the study area.

Although the Eo values are based on a shorter period of record than pan estimates, the annual figures are fairly close, with pan estimates being more than Eo values by 8.5%, 8.9% and 13.5% for Ol Joro Orok, Nanyuki and Lamuria respectively. Both estimates for Rumuruti differ by a small percent of 1.6, Eo being more than the pan estimate.

The altitude dependency of the annual potential evaporation estimates was established by Woodhead from the weighted regression as:

$$Eo = 2422 - 0.358h, \qquad r = 0.81, \qquad n = 78$$

with Eo in mm per annum

h = altitude in metres above mean sea level
r = correlation coefficient
n = number of sample points

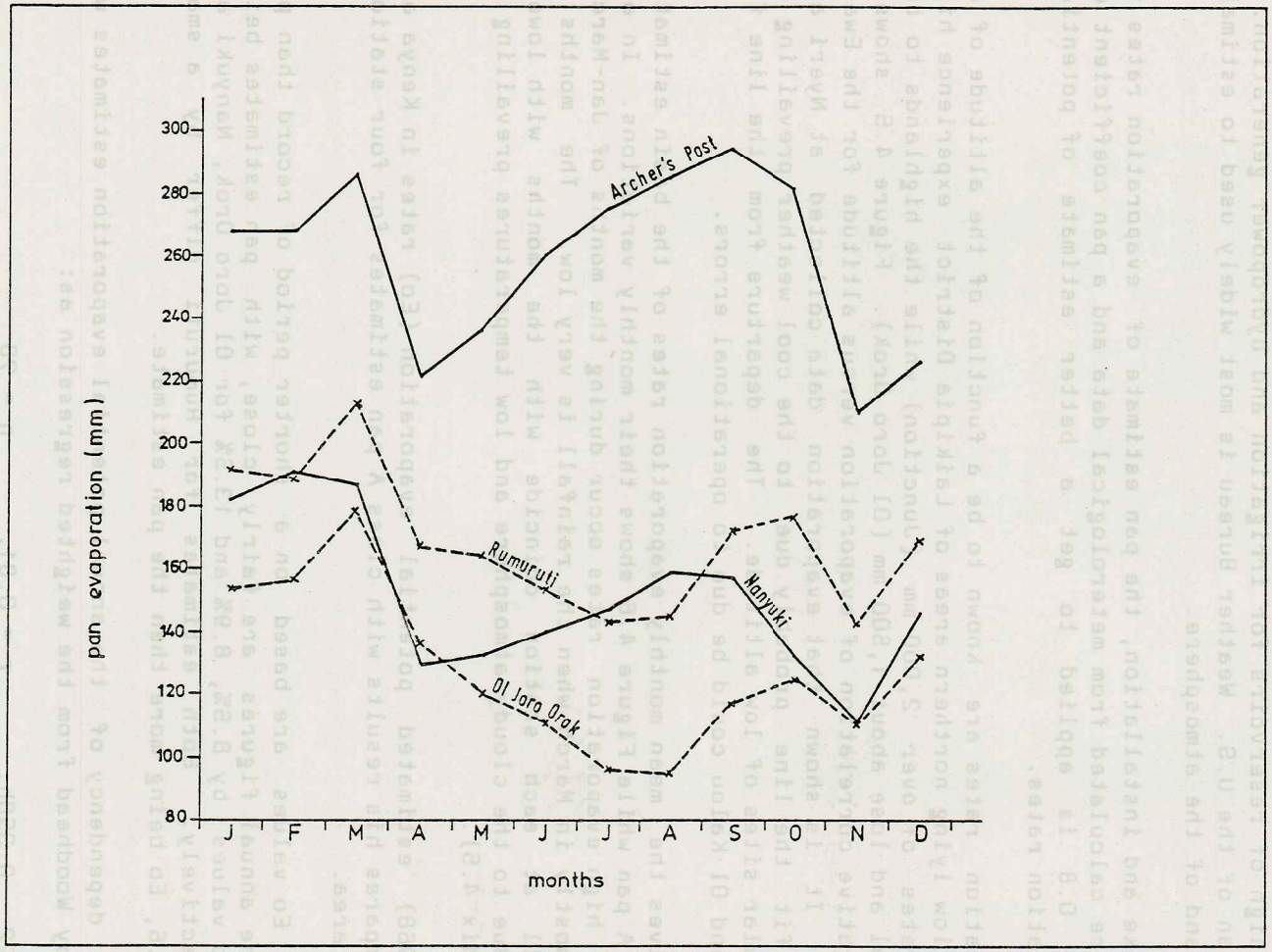


Fig. 4.6 Mean monthly pan evaporation

Estimates of actual evapotranspiration were made by Kiangi and Obasi (1973) using the soil moisture accounting method. For the area of study, mean annual estimates for four stations could be obtained from the National Master Water Plan, Stage 1 of 1980 (TAMS, 1980). The estimates are based on different periods of record.

Table 4.6 Compares the three estimates of Eo, class A pan and actual evapotranspiration with mean annual rainfall for the four stations.

Table 4.5 Mean Monthly Evaporation Rates in mm (Class A Pan)

Evaporation Station and Period of Record	Altitude in m	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Annual
Archer's Post (1946-85)	860	268	268	286	221	236	260	275	285	294	281	210	227	3110
Junction* (1950-85)	1680	202	201	220	178	166	152	145	154	191	199	167	175	2150
Rumuruti (1960-85)	1830	192	189	212	167	164	153	143	145	172	177	142	169	2025
Lamuria (1959-85)	1870	161	154	167	143	159	162	158	164	185	175	123	141	1892
Nanyuki Met (1946-85)	1950	182	190	187	129	132	140	147	159	157	132	111	146	1811
Ol Joro Orok (1946-85)	2360	154	157	178	136	120	111	96	95	117	125	110	132	1532

* Evaporation rates corrected for poor site using data (altitude and annual evaporation) for Rumuruti, Lamuria and Nanyuki.

Table 4.6 Comparison of Mean Annual Rainfall, Evaporation and Evapotranspiration

Station	Rain fall	Actual evapotranspiration	Penman evaporation (Eo)	Class A Pan evaporation
Rumuruti	672	691	2059	2025
Nanyuki	726	746	1663	1811
Lamuria	749	747	1667	1892
Ol Joro	986	965	1412	1532

It will be noted from the above table that actual evapotranspiration is closely related to the amount of rainfall while on the other hand, Eo and pan estimates indicate the potential water losses when water is unlimited.

4.5.1 Trend of Annual Evaporation

The annual evaporation totals plotted in Appendix 4.5 are fitted with a 5-year moving average and the general trend exhibited by the data is that of increasing annual evaporation from the early sixties to the present. Evaporation rates were low during the wet years of the fifties and sixties (Appendix 4.4). It then follows that years of minimum rainfall happen to be accompanied by maximum evaporation as has been experienced in the last few years of the eighties.

4.6 Surface Runoff

Laikipia District is drained mainly by two river systems:

- The Ewaso Narok to the west
- The Ewaso Ngiro to the East

The Ewaso Narok joins the Ewaso Ng'iro at the junction (station 5D5) where the system continues as the Ewaso Ng'iro river.

A brief description of these two systems is given in the following pages while making use of the major monitoring stations. For ease of reference, most tables of mean monthly discharge data and figures are presented in Appendix 4.6.

4.6.1 Ewaso Narok System (Including Pesi Catchment)

The Ewaso Narok system covers the whole of 5A sub-drainage area (Plate 4.1) and includes two perennial rivers, namely Ewaso Narok itself and Pesi. The Pesi river rises from the north-eastern edge of the Nyandarua mountain range and joins the Ewaso Narok river in the Narok swamp. Along the Pesi river itself is the Pesi swamp which extends from the Nanyuki - Nyahururu road bridge to the Nanyuki - Rumuruti road bridge. The two swamps are about 13 km apart. Investigations carried out between 1958-61 indicated that the Pesi swamp was about 9 km²*. River gauging stations exist on the above road bridges which monitor the river flow into and out of the swamp respectively. Runoff characteristics at the two gauging stations are described below. The Mutara river to the east of Pesi is perennial in the upper reaches but dries up a few kilometers downstream of the Nanyuki-Nyahururu road due to the presence of swamps.

During the rains, several otherwise dry river channels carry a lot of surface runoff to the main river.

There are about 20 river gauging stations (RGSs) monitoring the surface water resources of the Ewaso Narok system with the most downstream station, 5AC8, at the Junction monitoring a catchment area of about 3,300 km². Three of these RGSs are equipped with autographic water level recorders.

*This is the area flooded during high water levels in the river.

The perennial rivers have their source in the northern and northwestern ranges of Nyandarua mountains where the annual rainfall is over 1,000 mm.

In the middle reaches of the perennial Ewaso Narok and Pesi rivers, the swamps diminish river flows due to high rates of evapotranspiration. However, canals have been dug to pass some of the river flows along the swamps which is used for domestic and some irrigation purposes. Annual rainfall in the Narok swamp area is about 650 mm and this decreases to about 450 mm at the Junction.

Runoff characteristics of the Ewaso Narok system have been computed at five RGSs namely 5AA1, 5AC15 and 5AC8 on Narok river and 5AB3 and 5AB2 on Pesi tributary. A detailed analysis of these stations is found in Appendices 4.6.1 - 4.6.5.

4.6.2 Ewaso Ngiro System

The Ewaso Ng'iro system covers the whole of the 5B sub-drainage area and has a catchment area of 4560 km² at the Junction RGS 5D5. The rivers draining this system originate from both the northern Nyandarua mountain ranges and Mount Kenya where the annual rainfall is over 1,000 mm. This system has several perennial tributaries from Mount Kenya area which are fed by both rainfall and snow.

There are about 23 RGSs monitoring the surface water resources of this system, 15 of which are equipped with autographic water level recorders. Four of these recorders are on Naro Moru river alone which is a subject of special studies by a Swiss project.

Like its counterpart, the Ewaso Narok system, annual rainfall decreases from the mountainous region to the Junction (450 mm). In spite of this similarity however, the Ewaso Ngiro system contributes more dry season flow than Ewaso Narok system, but when it comes to flood flows, the two systems are at par (the 50-year flood).

Runoff characteristics of this system have been evaluated at three key regular gauging stations i.e. RGSs:

- 5BC4 on Ewaso Ng'iro itself at Ngare Ng'iro police post (Hulmes Bridge)
- 5BE20 on Nanyuki river upstream of the Nanyuki-Dol Dol road
- 5D5 before the Junction

A detailed analysis of these stations is found in Appendices 4.6.6 - 4.6.8

Appendix 4.6.9 describes in detail the RGD of the Ewaso Ng'iro at Archers Post, while Appendix 4.6.10 compares the flow characteristics at the Junction and Archer's Post.

4.6.3 Runoff Characteristics

Runoff characteristics of 9 monitoring stations are summarized in Table 4.7.

Table 4.7 Runoff Characteristics of Ewaso Ng'iro Basin (cumecs)

RGS	Ewaso Narok System					Ewaso Ng'iro System			
	5AA1 Narok	5AC15 Narok	5AB3 Pesi	5AB2 Pesi	5AC8 Narok (Junction)	5BC4 Ng'iro	5BE20 Nanyuki	5D5 Ng'iro (Junction)	5E3 Ng'iro (Archer's Post)
Catchment Area (Km^2)	577	860	319	412	3,290	1,870	860	4,561	15,300
Period of record	1945-85	5/1982-7/86	1959-85	1959-6/86	1951-85 (gap 1954-7)	1950-7/86 (gap 1955-9)	1960-7/86	1950-85 (gap 1954-7,1963)	1949-85 (gap 1975-80)
Mean monthly flow	1.910	1.696	1.260	0.736	3.840	3.280	5.800	7.880	21.040
Minimum flow	0.390	0.360	0.006	0.039	0.078	0.007	0.100	0.067	0.100
Minimum mean monthly flow	0.591	0.540	0.202	0.158	0.184	0.404	0.740	1.017	1.613
Daily flow duration									
- 95%	0.519	0.427	0.204	0.162	0.240	0.347	0.436	0.661	1.120
- 90%	0.556	0.501	0.219	0.182	0.302	0.468	0.794	0.955	1.730
Maximum flow	36	22	350	27	544	244	107	766	1897
50 - year flood	39	-	405	32	860	310	130	870	1400
100 - year flood	48	-	450	35	1300	380	144	1500	1800

The most important design parameters for water development projects are the:

- Minimum mean monthly flows and the
- 95 and 90% duration flows

These parameters indicate the available flow, 90 or 95% of the times, on long term average.

Taking the 90% flow duration level, this means that the indicated flows are equaled or exceeded 329 days in a year and only during 36 days of the year are these flows less than indicated.

The table indicates that the Ewaso Ng'iro system (SDS) produces three times as much dry season flow (90%) as Ewaso Narok system (SAC8) but the two systems are at par in the production of flood flows (50-yr) although their catchment areas are different in the ratio 1.4:1

Mean annual rainfall (1963-84) for the two systems amounts 649 and 677 mm respectively indicating that the rainfall input into the two systems is basically the same. Dry season flow on Ewaso Narok system is however greatly reduced by the presence of the two large swamps on Pesi and Ewaso Narok rivers but these swamps seem to have little effect on flood flows at SAC8.

The estimates made of the extreme flows i.e the minimum and maximum flows have been extrapolated from the rating curves which are limited to low and medium flows. That means the reliability of these figures is rather low because no gaugings exist to support them. However, they are presented here as a guide to the extreme flows that might be expected in the Ewaso Ng'iro basin.

4.7 Surface Water Quality

4.7.1 River Water

Samples were collected at 34 sites on the major rivers. The sampling sites are shown on Plate 4.1. In total 73 analyses are available (Appendix 4.7).

The ionic balances calculated for the complete analyses showed that only about 10% of the analyses can be considered as accurate. Therefore the quality of the available data is such that only orders of magnitude of the concentrations for the major ions are determined.

The total dissolved solid (TDS) content varies from 15 mg/l to 240 mg/l. In the majority of samples (58) the TDS however does not exceed 100 mg/l.

All samples contain sodium-bicarbonate water which is characteristic for the volcanic areas.

The fluoride concentration of river water ranges between less than 0.1 and 1.2 mg/l measured. Concentrations in excess of the WHO-guideline value (1.5 mg/l) were not measured. High iron concentrations (up to 100 mg/l) were recorded in samples from the Junction and Archer's Post. Higher iron concentrations, however influence only the aesthetic and taste characteristics of drinking water.

In general, water in the Ewaso Ng'iro streams is of good anorganic quality. High suspended load and possibly organic pollution (no data available) might limit direct use of surface water for drinking purposes. Fortunately these problems can be easily solved by simple filtration and subsequent chlorination.

As for the agricultural use, water from all sampled rivers is suitable for irrigation when judged by the salinity and Sodium Adsorption Ratio (SAR).

It must be stressed, though that above conclusions are based on few analyses. For the majority of the sampling sites only two analysis are available. Possible errors in the reported values must also be considered. More frequent sampling and accurate analyses (including bacteorological ones) are therefore required before the water from the rivers is taken in use either for domestic purposes.

4.7.2 Lake Water

One analysis of water from Lake Ol Bolossat is included in Appendix 4.7. Total Dissolved Solids (TDS) content of the sample is 1920 mg/l while the fluoride concentration is 3.6 mg/l. These values agree well with corresponding values of a sample taken in the beginning of the sixties which had a SAR ratio of 27 (MoWD, 1963).

Therefore, the water from Lake Ol Bolossat is unsuitable for human consumption and irrigation, and marginally suitable for stock watering.

5 HYDROGEOLOGY

5.1 Previous Hydrogeological Studies

The report "An Investigation into the Water Resources of the Ewaso Ng'iro Basin, Kenya" (Ministry of Works, 1963) deals generally with groundwater resources of the upper Ewaso Ng'iro catchment, which encompasses three quarters of the project area (Laikipia District). The conclusions are:

"The subsurface water resources of the upper catchment are substantial in that over a very high proportion of the area it is possible to sink boreholes and obtain useful supplies of groundwater. However, the quantity of water available from a single borehole is not large; averages from different parts of the upper catchment are between 1.36 and 4.55m³/h (available output) which is sufficient for domestic use, and in most cases for watering stock also. These yields are, however, insufficient for large-scale irrigation use".

The "Geology and Groundwater conditions of Central Laikipia" by C.M. Bristow and B.N. Temperley (1964) outlines the groundwater conditions in both central and greater part of Laikipia West. The conclusions pertaining to the volcanic area are:

"The Iguamiti, Marmanet, Aiyam and Ewaso Narok Phonolite groups yield the most groundwater and the Thomson's Falls Phonolites the least. One good aquifer only occurs in the Ndurumo Phonolites, and it is of restricted extent and lies at a depth of about 244 metres. Only one borehole draws a significant amount of water from the Laikipia Basalts and two draw good supplies from the Suguroi Phonolites. The Lariak Phonolites and the greater part the Laikipian Basalts do not descend deeply enough into the groundwater zone to contain any useful aquifers. No boreholes have been drilled into the Simbara Basalts but, based on drilling results in other parts of Kenya, good supplies should be obtainable from them.

As the principal aquifers are old land surface materials which include buried alluvial deposits in old watercourses that followed the sinuous edges of lava flows, the aquifers of today must include narrow winding zones of relatively high permeability which can be discovered only after the distribution of boreholes has become denser than it is now.

Groundwater in Basement System areas appears to have two principal modes of occurrence. One is typical of high ground where the depth of weathering is shallow and the degree of decomposition of rocks is sufficiently limited that succeeding formations of different kinds have widely different permeability. The other is typical of valley bottoms where deep and advanced sub-surface decay has produced a thick zone of more or less permeable material".

The geological reports published by the Geological Survey of Kenya (see Chapter 2.1) give a brief summary on groundwater availability for each corresponding sheet map. It is worthy to note that Shackleton (1946) drew attention to the particularly low yields of boreholes in the Basement System area and to the care with which they should be sited. He referred to the very shallow depth of the water table in the Rumuruti Phonolites and to the poor groundwater prospects of boreholes drilled into the Thomson's

Falls Phonolites and the higher permeability of the basalts. He anticipated good borehole results near faults in the scarp zone at the western edge of Laikipia by analogy with somewhat similar conditions west of Nairobi.

In the report "A Pre-investment study of Human and Natural Resources in Laikipia District (1983)" by Arid and Semi-Arid Lands Branch of the Ministry of Agriculture, groundwater was dealt with. The conclusion reached at is that "there should be ample groundwater for substantially increasing the number of boreholes. There is no indication that sufficient yields can be obtained for large-scale irrigation. The yields of some boreholes could support minor irrigation, but the quality of water for irrigation ranges from suitable to unsuitable among individual boreholes. The water from boreholes is suitable for livestock but its suitability for human consumption is largely related to the fluoride content. Greater reliance upon boreholes for non-irrigation purposes should be encouraged to maximize the potential of river water for irrigation.

In the report "The use of isotopes, hydrochemistry and geophysics in groundwater research in Laikipia District, Kenya" (1986) by Schotterer and Muller, Institute of Geography, University of Bern, groundwater was dealt with. The conclusions reached at are that only a limited recharge of groundwater in extended areas of the Laikipia District takes place today. In the rainforest of Mount Kenya and the Dol Dol region young, rechargeable groundwaters (<30 years) can be found, but natural outflows are rare. The main groundwater reservoirs were formed thousands of years ago: water in the area around Nanyuki has an age of 4,000 to 9,000 years while samples taken in the Mukutan gorge, east of the Lariak-Sipili high, have ages of 10,000 years. The water-quality is generally good and, with few exceptions, also suited for agricultural purposes. For water conservation it has to be considered that the yield from borehole waters is poor, and since up to now very little is known about the size of the reservoirs, groundwater exploitation should be handled very carefully and with the utmost responsibility.

5.2 Available Data

5.2.1 Landsat Data and Aerial Photographs

Landsat MSS and TM data on a scale 1:250,000 are available. The former and the latter cover the eastern and western parts of the project area, respectively and are overlapping approximately along the Mutara river. The study of the imageries yielded information on the major drainage pattern, vegetation cover, lithological boundaries between Basement System and volcanic rocks, different phonolites of Rumuruti Group (Table 2.1), Laikipian Basalts and Rumuruti Group Phonolites, Thomson's Falls and Rumuruti Group Phonolites and Sipili Trachytes and Rumuruti Group Phonolites. The main faults were easily identified.

Aerial photo-interpretation was done in the areas where more detailed investigations were to be carried out: namely Kinamba, Sipili, Ngomongo, Kandoro and Kanyingi (Laikipia West), and Lariakorok, Kopio, Osoit Oudo and Musul (Laikipia East). The available photographs are on a 1:50,000 scale. Photo-geological maps were produced (see Appendix 3.2). The aerial photo-interpretation helped in choosing the exact areas for geophysical surveys and identified the problem to be solved in each case.

5.2.2 Boreholes

During the inventory of the study, 266 boreholes were traced in the files of the Ministry of Water Development (Appendix 5.1); 27 of them could not be traced in the field. The Water Resources Assessment Project selected 10 areas for additional boreholes (Table 5.1 and Figure 1.2). The selection was based on the local water demand.

Detailed investigations were carried out in the following locations: Rumuruti, Salama, Sipili and Kinamba (Laikipia West) and in Il Ngwesi, Mukogodo and Il Digiri locations (Laikipia East). Areas for geophysical investigations were identified by means of interpretation of aerial photographs. Five drilling sites were selected in West Laikipia and three in East Laikipia.

Table 5.1 Selected Areas for Additional Boreholes.

DIVISION	LOCATION	AREA (VILLAGE)
Rumuruti	Rumuruti	Ngomongo
	Salama	Kandoro
		Kanyingi
Ngarua	Sipili	Bondeni
	Kinamba	Mwenje
Mukogodo	Il Ngwesi	Lariakorok
	Mukogodo	Kopio
		Osoit Oudo
	Il Digiri	Lobor Soit
		Musul

5.2.3 Well-test Data

The tested yields for the existing boreholes, as listed in Appendix 5.1 are based on the capacity of the pump since the drawdowns were measured only in eight boreholes: C4724, C4725, C4726, C4727, C4737, C5019, C5069 and C5360. The test pumping data obtained from two boreholes (C5069 and C5360) could be interpretated with difficulties. The project test pumped five additional boreholes, C555, C887, C957, C2895 and C2858.

The well test data were analyzed using Jacob's and Theis' methods for pumping and recovery phases, respectively (Appendix 5.2). The transmissibility values obtained from the recovery phase are preferred to the ones obtained from the pumping phase since the latter values are more sensitive to fluctuating pump discharges. This does not apply in the case

Table 5.2 Chemical Data Collected Before WRAP Project

B.H No.	pH	EC (uS/cm)	mg/l												Hardness ($CaCO_3$)	TDS (mg/l)	Aquifer System
			Na	K	Ca	Mg	Fe	Mn	Cl	HCO_3	SO_4	NO_3	F	SiO_2			
P126	-	-	-	-	74	30.3	0.8	-	46	227	72	0	0.6	28	310	460	2
P158	8.4	-	-	-	-	-	0.4	-	24	-	10	-	5.3	36	15	436	1
C23	7.7	-	-	-	-	-	0.16	-	19	-	48	-	6.5	3	186	300	2
C28	-	-	-	-	45	18	0.16	-	19	168	48	Trace	0.65	30	186	-	2
C37	8.0	-	-	-	-	-	0.4	-	65	365	15	Trace	3.0	18	30	570	1
C147	7.3	-	-	-	-	-	0.15	-	13	234	21	-	3.3	38	40	330	1
C342	8.6	1000	226.4	3.9	1.2	2.9	0	0	115	310	24.5	-	1.9	30	15	680	1
C396	7.3	-	-	-	-	-	1.0	-	206	412	106	-	2.8	24	90	960	1
C555	7.1	-	-	-	-	-	0.6	-	81	602	28	-	2.3	18	90	880	1
C913	-	650	-	-	4.6	1.1	0.1	0.1	1.0	-	-	-	-	-	16	397	1
C1217	7.1	-	-	-	-	-	1.8	-	5.0	276	Trace	0	0.6	40	50	360	1
C1565	8.7	-	-	-	-	-	0.55	-	299	456	177	0	6.5	6	0	1325	1
C1600	8.5	-	-	-	-	-	0.45	-	98	294	128	-	2.8	13	15	690	1
C1702	7.8	1330	-	-	-	-	-	-	177.5	-	-	-	2.06	-	178	-	1
C1785	8.8	-	-	-	1.0	-	Trace	-	21	244	Trace	-	2.0	2	9	80	1
C1813	7.35	-	-	-	11.6	4.9	Trace	-	15.6	46.8	8.5	-	0.9	2	42.9	87	2
C2188	7.5	-	-	-	185	8.8	1.6	-	316	378	40	-	1.0	3	498	1420	2
C2280	8.6	730	164	9.2	12.8	1.9	0.1	0	30	314	12.5	-	1.5	25	40	500	1
C2375	7.8	-	-	-	-	-	0.5	-	67	566	35	-	2.1	18	120	770	1
C2561	7.1	-	-	-	-	-	0.6	-	86	389	62	-	2.2	38	80	710	1
C2562	8.7	-	-	-	-	-	0.3	-	186	314	52	0	13.2	13	10	1050	1
C2576	7.9	-	-	-	-	-	1.6	-	Trace	Trace	0	0	3.2	30	30	435	1
C2676	7.1	-	-	-	-	-	7	-	2230	2340	240	-	2.6	260	400	7550	1
C2803	7.8	-	-	-	-	-	7	-	390	3290	320	-	1.3	520	1987	5550	1
C2858	7.3	-	-	-	-	-	0.7	-	13	-	0	-	0.2	50	30	250	1
C2869	7.5	-	-	-	-	-	15	-	580	3650	280	-	2.5	260	450	6150	1
C3022	7.3	-	-	-	-	-	-	-	77	-	62	-	0.6	45	400	640	2
C3533	9.6	-	-	-	-	Trace	-	-	7	346	Trace	-	0.5	Trace	Trace	100	1
C3555	7.9	0	-	-	75	Trace	Trace	-	39	318	Trace	-	1.0	40	356	175	1
C3563	7.9	0	-	-	20	-	Trace	-	117	410	-	-	1.4	25	48	350	1
C3704	8.0	420	46	8.5	21	11.5	0.1	0	14	212	4	-	1.6	30	100	306	1
C3761	9.0	845	36	11	4	0	6	-	29	285	25	0	4.3	30	30	526	1
C3857	7.9	1020	312	31	15	8	0.3	-	47	590	33	0.01	2.3	70	76	650	1

of borehole CS069 since the measured residual drawdowns are suspicious. The specific capacity values have been calculated.

5.2.4 Groundwater Levels

The data on water struck and water rest levels are tabulated in Appendix 5.1. The water struck level corresponds to the depth below the ground level at which ground water is encountered. The water rest level represents the final level to which groundwater rose or fell. The groundwater level elevations above mean sea level were estimated from the 1:50,000 topographical sheet maps.

The water rest levels listed in Appendix 5.1 were recorded during the completion of the boreholes. There is no record of any checks having been carried out during the subsequent history of the boreholes. Thirty boreholes were selected for regular monitoring of groundwater levels. The measurements were being taken once a month, depending on the accessibility of the borehole sites.

5.2.5 Chemical Data

Before the project began its activities in Laikipia District, water samples had been collected for chemical analyses from thirty three boreholes (Table 5.2). The project collected additional water samples for chemical analyses from forty nine (49) boreholes, one well (Table 5.3) and 24 springs (Table 5.4).

The Geographical Institute of the University of Bern collected 37 samples for isotope analyses (Schotterer and Muller, 1985). The analyses of tritium, oxygen 18, deuterium, carbon 13 and 14 were done in Switzerland. The Water Resources Assessment Project (WRAP) has collected more isotope samples to be analyzed in Switzerland.

The samples were taken from springs in the rainforest and alpine zone of the Naro Moro catchment, from springs and boreholes in the foothills and upper part of the plain between Naro Moro and Timau, from boreholes around Dol Dol and from boreholes and springs at Laikipia Ranching in Kinamba. The age of water from the rainforest, alpine zone and Dol Dol is less than 30 years. Samples from the foothills and plains indicate an age of around 4000 years while ground water from Kinamba is even about 10,000 years old.

The concentrations of oxygen-18 suggest that the main recharge zone lies between 3,000 and 3,500 m altitude. However, recharge of groundwater in the plains took place about 4,000 years ago when different climate conditions prevailed. In that time, it was probably more humid and the oxygen-18 concentrations were lower. Therefore no firm conclusions on the elevation of the main recharge zone can be drawn based on available isotope data.

Current climatic conditions however suggest that the main zone of infiltration coincides with the humid and semi-humid zones depicted on Figure 1.3. Those zones roughly coincide with the Middle and Upper Volcanic Slopes being situated above 2,100-2,500 m. Actual monthly rainfalls in the humid and semi-humid zones exceed potential evapotranspiration for 2-3 or more months per year. During these wet months there is ample opportunity for recharge.

Table 5.3 Chemical Data Collected by WRAP in Boreholes and one Well

B.H No.	Location	Date of Sampling	pH	EC (mS/cm)	mg/l											Hard-ness ($CaCO_3$)	TDS (mg/l)	Aquifer System
					Na	K	Ca	Mg	Fe	Mn	Cl	HCO_3	SO_4	NO_3	F	SiO_2			
C45	Ndaragwa	30.10.85	8.4	0.350	-	-	20	12	0.1	0.01	11	204	3.5	-	1.2	-	98	210	1
C66	Leshau	28.10.85	8.4	0.620	-	-	12	20	0.17	0.01	45	110	10.7	-	0.88	-	112	372	1
C150	Borana Farm	17.10.85	9.0	0.600	-	-	13.6	15.5	0.98	0.01	48	298	9.1	-	0.44	-	98	360	1
P152	Nakuru	2.11.85	8.6	0.830	-	-	29	11	0.1	0.01	30	340	15	-	1.2	-	118	498	1
C296	Mutara Ranch	1.11.85	7.9	0.860	-	-	28	22	0.1	0.01	76	380	37	-	1.2	-	160	516	1
C297	Mutara Ranch	1.11.85	8.3	0.700	-	-	28	15	0.49	0.01	48	374	15.7	-	1.4	-	130	420	1
C309	Tharua	22.10.85	8.9	1.300	-	-	6.4	9.7	0.1	0.01	49	424	22	-	1.0	-	56	780	1
C337	Rumuruti	1.11.85	8.5	0.500	-	-	25	10.7	0.1	0.01	18	260	11	-	1.8	-	106	300	1
C342	Narok Ranch	25.3.86	8.3	0.799	160	13	0.02	1.7	0.3	0.02	38	326	19	0.07	2.1	-	34	479	1
C372	Dol Dol	18.10.85	7.9	0.650	-	-	75	36	0.1	0.01	33	306	60	-	2.0	-	336	390	2
C373	Nanyuki	30.10.85	8.2	0.630	-	-	42	15	0.13	0.01	24	350	12	-	1.7	-	164	378	1
C523	Nanyuki	2.11.85	8.6	0.550	-	-	22	18	0.1	0.01	42	294	11	-	1.1	-	126	330	1
C555	Ol Pejeta Ran.	22.8.86	8.1	1.560	356	20	36	22	<0.1	0.01	175	550	4.7	0.08	2.1	42	231	937	
C571	Borana farm	17.10.85	8.3	0.460	-	-	24	24	0.13	0.01	30	252	4.1	-	0.35	-	156	276	1
C611	Ongata Weregoi	12.1.86	8.3	0.600	140	6	5.4	2.8	1.2	0.01	74	222	22	2.7	0.8	-	34	360	1
C674	Kamuaki Farm	18.10.85	7.4	0.540	-	-	42	21	0.24	0.01	54	178	51	-	0.41	-	190	324	1
C690	Nanyuki	30.10.85	8.3	0.640	-	-	36	17	0.11	0.01	29	344	14	-	1.3	-	160	384	1
C887	Solio Ranch	27.6.86	8.1	1.715	320	18	1.6	2.6	0.3	0.02	119	580	50	0.01	0.97	36	42	1029	1
C887	Solio Ranch	27.8.86	8.3	1.535	280	20	4.9	4.7	1.7	0.06	122	506	39	0.02	1.12	-	46	922	1
C913	Sipili	10.12.85	8.8	0.800	-	-	2.4	1.0	0.2	0.01	11	330	5.6	-	0.4	-	10	480	1
C932	Kiboke Farm	22.10.85	8.9	0.670	-	-	21	14.8	0.18	0.01	33	304	20	-	1.3	-	114	402	1
C1224	Ol Ng'arua	28.10.85	6.7	0.195	-	-	7.2	7.8	0.63	0.01	22	66	11	-	0.3	-	50	117	1
C1230	Borana Farm	13.10.85	7.8	0.600	-	-	71	27	0.1	0.01	55	280	40	-	0.41	-	286	360	2
C1381	Salama	24.10.85	8.5	0.640	-	-	22	12	0.12	0.01	46	316	21	-	0.70	-	102	384	1
C1498	Nanyuki	18.10.85	8.4	0.860	-	-	66	31	0.04	0.01	53	82	324	-	0.55	-	290	516	2
C1646	Narok Ranch	11.1.86	8.0	0.560	130	17	5.9	2.5	0.1	0.1	35	192	11	0.63	0.4	-	38	336	1
C1702	Segera Ranch	1.11.85	8.8	0.860	-	-	12	8.7	0.14	0.01	66	402	28	-	1.5	-	66	516	1
C1767	Pesi	1.11.85	9.0	0.880	-	-	17.6	16	0.1	0.01	8	376	40	-	1.3	-	110	528	1
C1785	Solai	27.3.86	9.2	0.640	163	4.4	0.1	0.1	0.3	0.02	27	276	7.8	0.04	2.8	-	1	384	1
C1819	Ol Maisor	25.3.86	9.0	1.960	370	13	1.1	0.1	0.3	0.01	324	200	166	0.07	3.8	-	5	1176	1
C1896	Marmar	26.3.86	8.4	1.295	260	7.4	0.9	0.3	0.3	0.02	118	210	118	0.06	3.4	-	10	777	1
C2023	Gatarakwa	30.10.85	8.4	0.300	-	-	23	18	0.3	0.01	14	190	1.5	-	0.6	-	134	180	1
C2135	Oljogi Ranch	18.10.85	7.9	0.980	-	-	120	37	0.39	0.01	66	302	319	-	0.54	-	454	588	2
C2259	Sosian	26.3.86	8.6	0.747	159	2.2	0.5	0.2	1.0	0.05	59	258	20	0.02	1.6	-	3	448	1

- Not determined

Cont. Table 5.3 Chemical Data Collected by WRAP in Boreholes and one Well.

B.H No.	Location	Date of Sampling	pH	EC (mS/cm)	mg/l												Hard-ness ($CaCO_3$)	TDS (mg/l)	Aquifer System
					Na	K	Ca	Mg	Fe	Mn	Cl	HCO_3	SO_4	NO_3	F	SiO_2			
C2315	Timau	27.3.86	8.0	0.462	89	11	2.5	1.9	0.5	0.01	24	222	7.2	0.03	0.85	-	30	277	1
C2318	Lariak	28.3.86	8.2	1.660	250	43	68	18	1.2	0.06	200	442	85	0.01	3.5	-	264	996	1
C2369	Karungu	22.10.85	9.0	0.400	-	-	16	15	0.17	0.01	15	226	4	-	1.0	-	104	240	1
C2381	Sironi	29.10.85	7.9	0.330	-	-	9.6	11	0.29	0.01	8	198	0.86	-	0.24	-	68	198	1
C2400	Il Pinguin	13.10.86	7.6	0.550	170	21	5	1.4	0.1	0.1	34	296	11	0.87	0.32	-	26	330	1
C2594	Nanyuki	2.11.85	9.0	0.690	-	-	30	11	0.04	0.01	61	360	32	-	1.2	-	74	414	1
C2676	Kirimun	26.3.86	7.6	1.220	170	24	14	8.3	0.4	0.01	95	216	69	0.10	0.85	-	108	732	1
C2727	Kumuruti	11.1.86	9.0	0.650	180	6	1.5	0.1	1.3	0.4	48	346	19.6	0.01	1.1	-	2	390	1
C2805	Narok Ranch	26.3.86	8.9	0.890	180	5	0.9	0.2	0.2	0.01	79	290	32	0.08	0.55	-	9	534	1
C2858	Sirioni	14.8.86	7.7	0.235	67	11.4	2.5	1.6	0.7	0.23	12	157	2.3	0.02	0.29	31	24	200	1
C2858	Sironi	2.9.86	7.9	0.230	59	8.4	2.6	1.4	0.5	0.01	12	154	1.7	0.03	0.27	31	26	200	1
C2889	Kieni Farm	25.3.86	8.3	0.860	190	15.6	4.4	1.9	0.4	0.01	53	368	23	0.08	2.6	-	36	516	2
C2895	Ol Maisor	20.7.86	7.4	1.355	200	15	4.3	2.5	0.6	0.02	27	414	25	0.9	1.2	40	42	813	1
C3420	Kimanjo	24.10.85	8.8	1.060	-	-	89	59	0.08	0.01	109	250	171	-	0.75	-	452	636	2
C4180	Nyahururu	30.10.85	8.4	0.200	-	-	11.2	5.8	0.1	0.01	18	82	2.3	-	0.21	-	52	120	1
C4683	Ol Pejeta	2.11.85	8.9	1.180	-	-	31	17	1.2	0.01	32	234	84	-	3.2	-	144	708	1
C5069	Kinamba	28.10.85	8.0	0.250	-	-	4.8	5.3	0.07	0.01	45	76	1.0	-	0.33	-	78	150	1
C5140	Mukogodo	9.1.86	7.9	1.100	82	20	163	70	3.7	0.4	171	458	60	2.0	0.22	-	624	660	2
C5197	Ol Kinyei	6.4.86	8.4	0.980	118	14	69	39	0.2	0.07	151	254	70	0.06	1.4	32	392	588	2
Well	Mwenje	28.10.85	7.6	0.450	-	-	13	9.2	0.25	0.01	120	80	4.7	-	0.4	-	70	270	1
	Sirioni	14.8.86	7.7	0.235	67	11.4	2.5	1.6	0.7	0.23	12	157	2.3	0.02	0.29	31	24	200	

- Not determined

Table 5.4 Chemical Data Collected by WRAP in 24 Springs

Name of Spring	Date of Sampling	pH	EC (mS/cm)	mg/l											Hard-ness ($CaCO_3$)	TDS (mg/l)	Aquifer System
				Na	K	Ca	Mg	Fe	Mn	Cl	HCO_3	SO_4	NO_3	F	SiO_2			
South Aiyam	28.10.85	8.7	0.335	-	-	0.4	8	0.4	0.01	12	200	1.8	-	0.25	-	34	201	1
Il pinguin	26.3.86	9.2	0.960	190	5	0.2	0.1	0.4	0.06	79	312	28	0.06	1.9	-	8	576	1
Bakuli	12.1.86	7.8	0.580	-	-	48	20	1.1	0.09	57	238	13.8	-	0.8	-	202	340	1
Kiabogo Mastoi	28.10.85	7.8	0.540	-	-	25	18	0.31	0.01	55	188	38	-	0.4	-	136	324	1
Large Scale	25.10.85	7.9	0.090	-	-	4.4	9.5	0.13	0.01	6	46	1.2	-	0.21	-	50	54	1
Tandare	28.10.85	8.5	0.350	-	-	15	12	0.23	0.02	19	194	1.1	-	0.2	-	86	210	1
Njonjo Girls	25.10.85	7.2	0.075	-	-	6.8	8	0.14	0.01	5	42	1.2	-	0.16	-	50	45	1
Marmanet	28.10.85	8.3	0.260	-	-	8	11	0.74	0.01	17	134	1.1	-	0.38	-	64	156	1
Kwa Nugu	24.10.85	7.0	0.095	-	-	3.6	6.1	1.1	0.01	4	52	0.3	-	0.22	-	34	57	1
Muruku	24.10.85	7.6	0.340	-	-	12	20	2.9	0.8	13	196	0.3	-	1.1	-	112	204	1
Bustani	24.10.85	7.4	0.450	-	-	5.6	7.3	1.4	0.15	67	166	3.1	-	0.44	-	44	270	1
Ngusishi	18.10.85	7.4	0.076	-	-	12	2.2	0.48	0.01	4	42	0.6	-	0.27	-	42	46	1
Ngarua	28.10.85	7.5	0.330	-	-	5.6	5.8	1.1	0.01	23	158	7.3	-	0.39	-	38	198	1
Shauri	29.10.85	6.9	0.130	-	-	8	4.9	0.45	0.01	10	64	4	-	0.27	-	40	78	1
Shereta	28.10.85	8.3	0.740	-	-	9.6	7.3	0.75	0.01	21	244	8.7	-	0.75	-	54	444	1
Kandoro	24.10.85	7.4	0.200	-	-	13	9.2	1.0	0.01	21	80	10	-	0.55	-	70	120	1
Wellmount	28.10.85	8.2	0.105	-	-	5.6	4.4	0.1	0.01	6	60	2.3	-	0.45	-	32	63	1
Mutanga	28.10.85	7.2	0.200	-	-	5.6	3.9	0.5	0.01	19	94	9.3	-	0.47	-	40	120	1
Reuben	24.10.85	7.1	0.120	-	-	12	5.3	0.1	0.01	5	66	0.3	-	0.3	-	52	72	1
Sukuta Marmar	11.1.86	8.5	0.510	130	5	1.1	0.3	0.3	0.1	42	264	24	0.35	0.5	-	4	306	1
Sukuta Mugie	11.1.86	8.5	0.510	120	6	2.5	0.3	0.1	0.1	29	276	8.6	0.05	0.7	-	2	306	1
Sukuta Naibor	11.1.86	8.1	0.500	130	6	1.8	0.5	0.7	0.1	31	282	7	0.07	0.6	-	8	300	1
Mbugua	25.10.85	7.5	0.060	-	-	1.6	5.3	0.22	0.01	9	20	1.7	-	0.14	-	26	36	1
Kirimun	13.1.86	8.1	0.600	150	11	4.5	1.9	0.2	0.1	69	250	20	1.4	0.55	-	24	360	1

- Not Determined

5.3 Groundwater Occurrence

Groundwater occurrence is controlled by the available recharge and geological conditions of the area. The eastern part of the area is composed of the metamorphic rocks of the Basement System, while the southern and western parts are composed of volcanic rocks. Fresh metamorphic and volcanic rocks can be considered as impervious, without storage capacity. Therefore, exploitable groundwater resources in Laikipia District are found in:

- fissured and/or weathered zones in the metamorphic and volcanic rocks;
- sediments (old land surface deposits) interbedded between the lava flows.

5.4 Aquifer Conditions and Systems

The analysis of the aquifer conditions is based on the available geological information (Chapter 2) and borehole data (Appendix 5.1).

The project area extends eastward from the eastern edge of the Rift Valley. The western zone is covered by volcanic rocks which overly the Basement System rocks. The latter outcrop in the eastern part of the area (Plate 5.2).

The deepest borehole, C2414 in Ol Pejeta area was drilled to a total depth of 317 metres. The average depth of the boreholes is about 120 metres, while the majority (70%) of them do not exceed a total depth of 150 metres below surface.

On the basis of the available hydrogeological data, two aquifer systems can be distinguished (Figure 5.1).

1. A system comprised of the fissured and weathered volcanics with interbedded old land surface deposits. This system can be considered as a regional aquifer system (System 1).

2. A system of fissured and/or weathered Basement System rocks. This system can be considered as a local aquifer system (System 2).

5.5 Regional Aquifer System (System 1)

A total number of 210 boreholes have been drilled in this system. The difference between the water struck and water rest levels (Appendix 5.1) is an indication that the aquifer is confined. The groundwater is interconnected through fissures and porous material which partly composes the old land surface deposits. This system is mainly recharged in the high areas where rainfall is high. This is the case in Mount Kenya, northern Aberdares and Marmanet-Ol Arabel areas (Plate 5.1). Ample infiltration is realized along the fault zones, mainly in the latter area. Part of the infiltrated water is discharged in numerous springs; they are found at Sukuta Mugie and Sukuta Marmar along the Rumuruti-Maralal road, at Kirimun and others, then in Swamps Pesi, Ewaso Narok and Suguta Naibor (Plates 5.1 and 5.2).

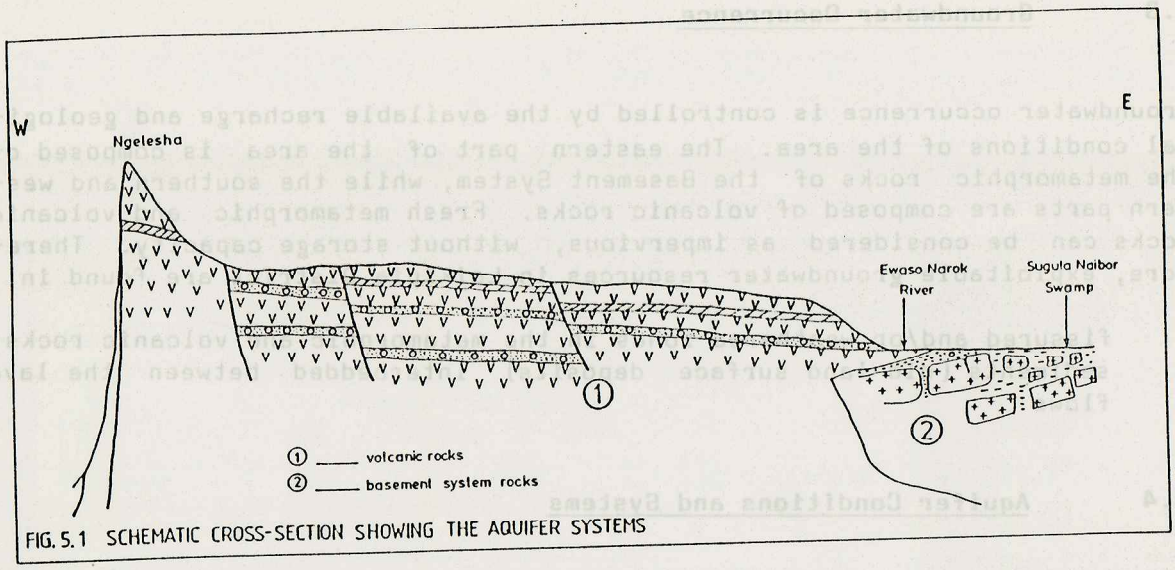


FIG. 5.1 SCHEMATIC CROSS-SECTION SHOWING THE AQUIFER SYSTEMS

5.5.1 Transmissibility, Specific Capacity and Yield

Even though 210 boreholes have been drilled in this system, hydrogeologic parameters were not determined due to the fact that these boreholes were never test pumped. And as such the yields shown in Appendix 5.1 and Plate 5.2 are based on the capacity of the pump. In view of the above, WRAP test pumped five boreholes C555, C887, C957, C2858 and C2895. The calculated hydrogeological parameters are shown in Table 5.5.

The lower Ewaso Narok Phonolites (C2858) have the highest value of transmissibility, Table 5.5. The Marmanet Phonolites (C2895), Olivine Basalts (C957) and Mount Kenya Volcanic Series (C887) have transmissibility values of the same order. But the borehole C555 sunk in the Olive Basalts, just near the Basement/Volcanic contact (a long distance from the recharge area) has the lowest transmissibility value. How representative these values are for the areas concerned is unknown.

The relationship between specific capacity and transmissibility can be estimated from the Jacobs approximation for unsteady state flow where,

$$s = \frac{2.3\,Q}{4\,T} \log \left[\frac{2.25\,Tt}{r^2 S} \right]$$

Taking as average hydrogeological parameters:

$S = 10^{-3}$ for confined aquifers and

$S = 7.5\ 10^{-2}$ for unconfined aquifers;
$T = 20\ m^2/day$;

t = pumping period = 1 day;

then the above equation reduces to

$$\frac{Q}{s} = \frac{T}{0.9}$$ for unconfined aquifers and

$$\frac{Q}{s} = \frac{T}{1.2}$$ for confined aquifers

Table 5.5 Calculated Hydrogeological Parameters

Borehole Number	Locality	Transmissibility T M^2/day	Specific Capacity Q/s M^2/day	Yield at a Drawdown of 10 Metres M^3/h	Specific Capacity Calculated from $\frac{Q}{S} = \frac{T}{1.2}$
C555	Ol Pejeta	5.4	0.6	0.3	4.5
C887	Solio Ranch	21.3	4.7	2.0	17.8
C957	Ol Pejeta	13.4	3.8	1.6	11.2
C2858	Sironi	30.7	4.6	1.9	25.6
C2895	Ol Maisor	14.8	2.5	1.0	12.3

As very little is known about the quality of construction of the tested wells the calculation of specific capacity out of well drawdown data is suspect. More reliability is attached to the calculation of transmissibility from the Theis recovery method. Specific capacities calculated with the above approximation for confined aquifers are shown in Table 5.5 (last column). The specific capacities calculated from drawdown data are a factor 3 to 7 smaller than those calculated in the last column. This indicates that well losses in these specific boreholes are considerable. Well executed drilling could improve yield of boreholes by the same factor.

Considering the data presented in Table 5.6, boreholes sunk in the Lower Ewaso Narok Phonolites, Olivine Basalts and Mount Kenya Volcanic Series have the same yields. The boreholes yields are lower in the Marmanet Phonolites. But taking into account the borehole yields based on the pump capacity (Appendix 5.1 and Plate 5.2), boreholes drilled in the Lower Ewaso Narok Phonolites, Marmanet Phonolites, Mount Kenya Volcanic Series, Olivine Basalts and the trachytes their yields will vary from 1 to 14 m^3/h (24 to 336 m^3/day). Boreholes have not been sunk in the Ngelesha Phonolites and the Rumuruti Forest Basalts. The Ol Arabel Tuffs yields are between 5.5 and 9.5 m^3/h (132 and 228 m^3/day). The Upper Ewaso Narok and Thomson Falls Phonolites have the poorest yields, 0.6 to 1.4 m^3/h (14.4 to 33.6 m^3/day) and 2 m^3/h (48 m^3/day), respectively.

5.5.2 Groundwater Levels and their Fluctuations

The water struck levels tabulated in Appendix 5.1 and shown on Plate 5.2 range between 18 and 266 metres below ground level. In several boreholes, water has been struck at two levels and in a few at three to five different levels. Due to lack of data, the depth to the water bearing layers (aquifers) within the Ngelesha Phonolites and the Rumuruti Forest Basalts is not known. The depth of aquifers within the Lower Ewaso Narok Phonolites varies from 55 to 214 metres with only two cases over 200 metres (C2218 and C2889). The depth of aquifers within the Marmanet Phonolites ranges between 66 and 237 metres with only one case, over 200 metres (C913). Boreholes drilled in the Upper Ewaso Narok Phonolites will encounter water

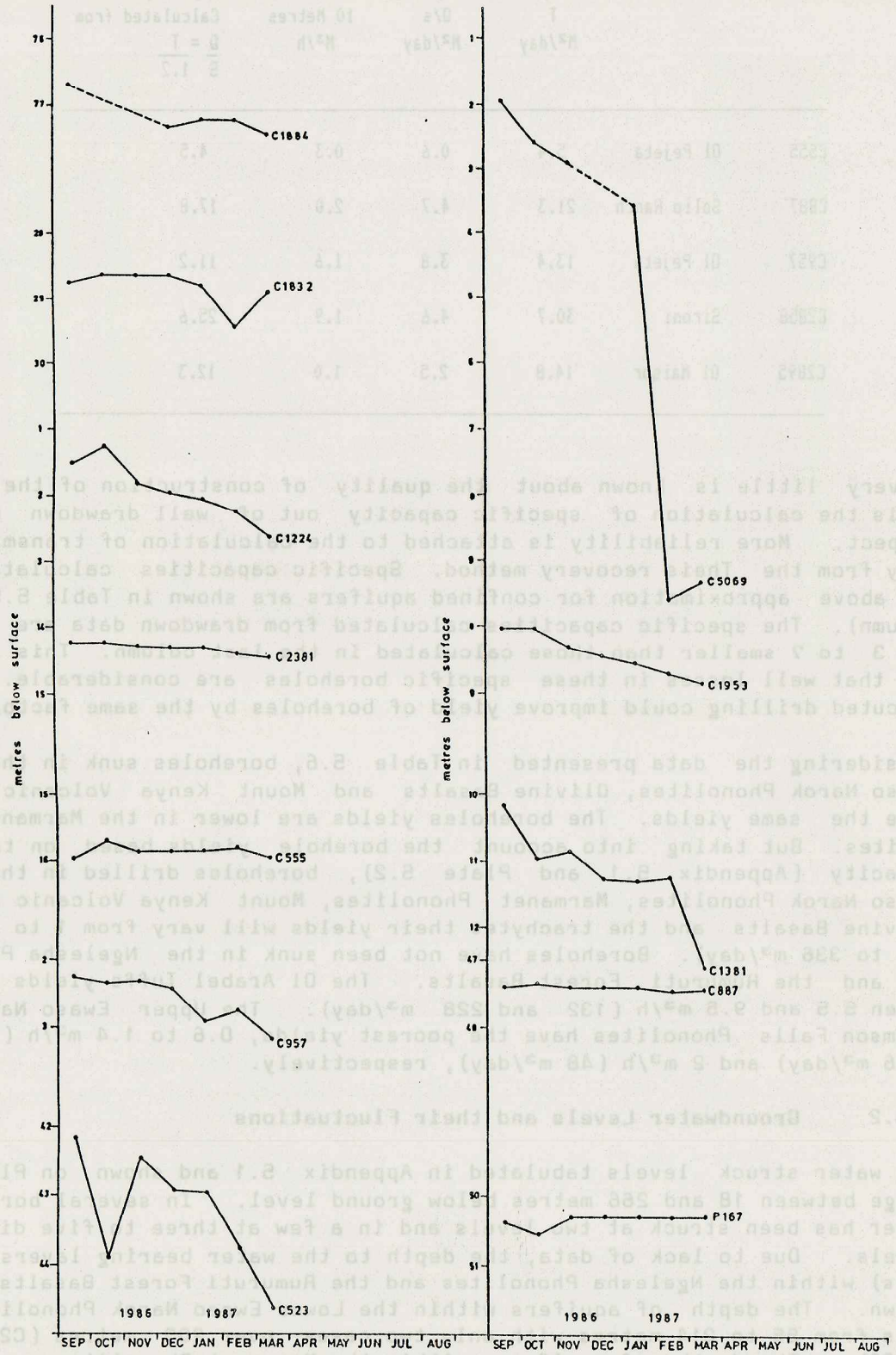


Figure 5.2 Well Hydrographs

between 122 and 183 metres deep and within the trachytes at a depth of 223 to 266 metres. Water bearing layers within the Thomson Falls Phonolites and Mount Kenya Volcanic Series are at relatively shallow depths from 18 to 111 metres and from 18 to 127 metres, respectively. Within the Olivine Basalts the aquifers are encountered between 50 and 199 metres and within the Ol Arabel Tuffs at a depth of about 100 metres.

The water rest levels vary from 7 to 123 metres below ground level. The depth to the water rest levels within the Ngelesha and the Rumuruti Forest Basalts is not known due to lack of data. But depth to the water rest levels within the other volcanic rocks are as follows: Lower Ewaso Narok Phonolites, 7 to 69 metres; Marmanet Phonolites, 23 to 76 metres; Upper Ewaso Narok Phonolites, 46 to 123 metres; the trachytes, 31 to 115 metres; Mount Kenya Volcanic Series, 32 to 73 metres; the Olive Basalts, 16 to 87 metres and Ol Arabel Tuffs, 50 to 79 metres.

A total of 21 boreholes and 2 wells have been monitored once per month for a period of 7 months. Twelve well hydrographs are represented, Figure 5.2. Boreholes C523, C1381 and C5069 are operational and their well hydrographs are not analyzed due to pumping effects.

The well hydrographs of the boreholes P167, C957, C887, C555, C2381, C1953, C1224, C1832 and C1884 have been analyzed. In boreholes C887, and C2381 groundwater level fluctuations are very small (0.11 to 0.21m) with peaks in October. In P167 and C555 variations are 0.25 and 0.24m, respectively. Minimum and maximum levels are recorded in October and February. In C957 and C1832 sharp drops are indicated in January, March and February respectively. The peaks in January and February in C1884 might be due to delayed recharge by the short rains. C1953 and C1224 have the same pattern with peaks in October which might be due to the short rains.

5.5.3 Groundwater Flow

Groundwater movement from recharge area to discharge area depends on the available recharge, the aquifer characteristics and the mode of discharge. In Laikipia District, these conditions are not uniform, mainly due to great variation in rainfall distribution and geological condition of the subsurface.

Groundwater recharged in the Mount Kenya and the Northern Aberdares flows in a north-westerly and north-easterly direction respectively (Plate 5.1). But groundwater recharged in the Marmanet-Ol Arabel area, partly flows in an easterly direction, while a part of it flows in a westerly direction which then flows north along the fault zones whose general trend is north-south. The general groundwater flow is north-eastward. The discharge areas mark either the Basement System - Volcanic rocks contact or the existence of old land surface deposits between two different lava flows. In some cases the fault zones which act as aquifers conduct water from high to low grounds.

For the determination of the rate of groundwater flow in System 1, the system has been divided into five sub-areas:

I. Nanyuki area
II. Engare Ngobit area
III. Suguroi - Segera area

IV. Marmanet - Rumuruti area
V. Sukuta Naibor-Marmar area.

The rate of groundwater flow is calculated for each sub-areas at the position of the 1,850 m piezometric line, see Plate 5.1.

I. **Nanyuki area**

No borehole has been test pumped in Area I. In the adjacent Area II, see Plate 5.1, the inferred shape and slope of groundwater contour lines are similar. There, two holes have been test pumped with calculated (boreholes C957 and C887) transmissivities of 13.4 and 21.3 m^2/day. In Area I, a transmissibility of 15 m^2/day has been assumed. The hydraulic gradient (i), determined from the groundwater contours (Plate 5.1) is 2.5×10^{-2}. Assuming an average width (W) of Nanyuki sub-area of 30 km, the application of Darcy's Law yields a flow rate (Q):

$Q = T.i.W = 15.0 \times 2.5 \times 10^{-2} \times 30 \times 10^3 = 11,000$ m^3/day (4.3 l/sec.km)

or 4.1×10^6 m^3/year.

II. **Engare Ngobit area**

The transmissibility in this area is taken at 20 m^2/day from two well tests (C957 and C887) see Plate 5.1. The hydraulic gradient (i), determined from the groundwater contours (Plate 5.1) is 1.3×10^{-2}. An average width (W) of 25 km is assumed: Hence

$Q = 20.0 \times 1.3 \times 10^{-2} \times 25 \times 10^3 = 6,500$ m^3/day (3.0 l/sec.km)

or 2.4×10^6 m^3/year.

III. **Suguroi - Segera area**

Although the well test resulted in a transmissibility of 5.4 m^2/day the value is thought not to be representative of the area under consideration. Borehole C555 is in the lower part of Area III. The calculation of the groundwater flow is carried out higher, in the area of boreholes C1918 and C2003, where gradients are steeper and similar to those of Areas I and II. A transmissibility value of T = 20 m^2/day is also taken as a reasonable value.

$Q = 20 \times 1.5 \times 10^{-2} \times 20 \times 10^3 = 6,000$ m^3/day (3.5 l/sec. km)

or 2.2×10^6 m^3/year.

IV. **Marmanet - Rumuruti area**

a) **Marmanet**

The transmissibility of the rocks comprising the aquifer in this area is taken as 25 m^2/day, borehole C2858 being more representative of the area of flow than borehole C2895, see Plate 5.1; the hydraulic gradient (i) as 2×10^{-2} and the average width (W) as 30 km. Hence

$Q = 25 \times 2 \times 10^{-2} \times 30 \times 10^3 = 15,000$ m^3/day (5.8 l/sec. km)

or 5.5 x 10^6 m^3/year

b) Rumuruti - Pesi

In this zone, the following parameters have been used, T=15.0 m^2/day (borehole C2895), i=1.7 x 10^{-2} and W = 27 km.

Q = 15.0 x 1.7 x 10^{-2} x 27 x 10^3 = 7,000 m^3/day (3.0 l/sec. km)

or 2.5 x 10^6 m^3/year

V. Sukuta Mugie - Kirimuni area

In this sub-area, the transmissibility of the rocks comprising the aquifer is assumed to be equal to the Rumuruti area, that is 15 m^2/day. The hydraulic gradient (i), obtained from the groundwater contours (Plate 5.1) is 6.0 x 10^{-3} and the average width (W) is taken as 20 km. Therefore, the flow rate (Q) is calculated:

Q = 15 x 6.0 x 10^{-3} x 20 x 10^3 = 2000 m^3/day (1.2 l/sec. km)

or 0.8 x 10^6 m^3/year

From the above calculations the total groundwater flow at the 1850 m piezometric line is in the order of 50,000 m^3/day or 18 x 10^6 m^3/year.

The flow rate in l/sec per km varies between 1.2 l/sec. km for Area V to 5.8 l/sec. km for Area IVa, for an average of about 4.3 l/sec. km at the 1,850 m piezometric line.

In Sub-area I, as groundwater flows in a north-westerly direction, some is discharged in numerous springs on the slopes of Mount Kenya and near or at the basement - lava contact (Plate 5.1). Below the 1,850 m piezometric line the gradient changes. Groundwater is lost as baseflow to the tributaries and to high evaporation rates in the Rongai - Burguret swamp and probably through evaporation after, reaching the basement-lava contact zone.

In sub-areas II and III, as groundwater flows in its north - easterly direction, some emerges as springs near the basement-lava contact zone. Due to very low flow rates in the low lying area, probably a considerable part of the groundwater is lost before as baseflow to the tributaries.
In sub-area IV, as groundwater flows in a north-easterly and an easterly direction part of it emerges as springs in the high lying areas while in the low zones losses mainly occur at swamps Pesi, Ewaso Narok and Suguta Naibor.

In sub-area V, the groundwater flow rate has minor variations. Groundwater flows in an easterly direction and its outflow is realized through numerous springs (Plate 5.1).

The piezometric lines on Plate 5.1 could not be drawn with very much detail as the data necessary was not available. Nevertheless, it shows clearly that the groundwater gradient below the 1850 m contour decreases by a faction two and consequently groundwater flow by the same factor assuming constant transmissibilities. In general, transmissibilities decrease in downstream directions away from the eruption centres as aquifers become

thinner and deposits finer. But transmissibilities of the plateau lavas underlying the Nanyuki-Rumuruti-Sukuta plains are probably rather constant. Therefore the groundwater flow in the regional aquifer system below the plains may be estimated at 1/2 x 18 = 9 Mm^3/year. The remainder is converted to baseflow or lost to evapotranspiration.

A more detailed piezometric map would probably show the piezometric lines to be hydraulically connected to the numerous streams crossing them perpendicularly. In the region above the 1,850 m line, groundwater contributes to the flows in the numerous streams and tributaries, eventually feeding the Ewaso Ng'iro river.

5.5.4 Discussion of Results

In the previous section it is calculated that the effective groundwater recharge above the 1,850 m piezometric contour line amounts to approximately 18 Mm^3/year Because of the considerable groundwater flow returning to the streams and tributaries above the 1,850 m line, the actual water infiltration must be many times higher. Furthermore it was argued that the main recharge zone is situated above the 2,100-2,500 contours, depending of exposure and location.

Within this context the following questions arise:

- What is the total recharge in the area above the 1,850 contour line?
- To where flows the groundwater which passes the 1,850 m contour?

- Recharge

Figure 6.2 (next chapter) shows three cross-sections in Laikipia for which 95% daily flows have been calculated. These flow rates occur only weeks or month after the end of the rainy seasons. They are typical dry season flows which are maintained by seepage from the riverbeds into the river. The 95% flow crossing the highest cross-section which roughly coincides with the 1,850 m contour, amounts to approximately 100 Mm^3/year. In fact this estimate of streamflow generated by groundwater is rather conservative. It could easily be double this amount, 200 Mm^3, which corresponds to the 70% probability level, exceeding the calculated groundwater flow above 1,850 contourline by a factor 10 to 20. The aquifers which generate baseflow are recharged during the rainy seasons by approximately the same amount as is lost to baseflow. So the total recharge to compensate for losses to groundwater flow and baseflow amounts to roughly 120 to 220 Mm^3/year. This roughly corresponds to respectively 5% and 9% of the rainfall on the 2,471 Km^2 area above the upper cross-section where rainfall is ca 1,000 mm/year. This recharge corresponds to 1.5-3 l/sec.Km^2. However, it must be stressed that only between 5 and 10% of the total (9 Mm^3/year) contributes to the deep regional system in the plains below, as downstream of the 1,850 m line this process of diminishing groundwater flow, due to seepage into the rivers, probably continues. As a result, only few springs are found on the boundary of the volcanics and the Basement Complex. Taking a groundwater flow of 9 Mm^3/year available in the plains with a surface area of approximately 3,200 km^2 corresponds to an available recharge to the deep aquifer system of 0.09 l/sec km^2.

- Groundwater Age

The age of water discharged from springs on the volcanic slopes of Mount Kenya at higher altitudes is generally less than 30 years. But the groundwater in the plains around Nanyuki has an age of 4,000 years or more. It is clear that the water emerging in these springs circulates through shallow systems while the water in the plains passes underneath, being part of the regional system.

The age of the groundwater under the plains is considerable. So, the question arises whether this is in agreement with the other hydrogeological characteristics of the area. Age is related to aquifer properties and travel distances. The following discussion is mainly to evaluate whether these relationships are consistent.

The travel distance between elevation of the main recharge zone at ca. 3,000 m and the plains around Nanyuki at about 1,900 m is approximately 25 km.

Simplifying the flow systems and considering only averages, a relationship can be established between the flow distance, the Darcy equation converted to actual velocity and the travel time in the deep aquifer system (water arriving in the plains).

In formula:

$$\frac{L}{a} = V = \frac{v_d}{p} = \frac{Ki}{p} = \frac{Ti}{Dp}$$

where, L = travel distance (m)
a = age of the groundwater (days)
v = actual velocity (m/day)
v_d = Darcy velocity (m/day)
K = coefficient of permeability (m/day)
i = gradient of the groundwater
p = effective porosity
T = transmissibility = KD (m^2/day)
D = mean aquifer thickness (m)

Leaving out the conversions, the equation reduces to:

$$\frac{L}{a} = \frac{Ti}{Dp}$$

Substituting L = 25,000 m; a = 4,000 x 365 days; i = 0.044 (slope of land surface) the equation presents a relationship between the remaining parameters T,D and p. Now a table can be made to estimate plausible values for these parameters. The values in Table 5.6 represent transmissibilities which are related to aquifer thickness (D) and porosity (p) for a travel time of 4,000 years.

$$T = \frac{Dp}{2.6}$$

The results from the only four pumping tests available, suggest values of 10 to 25 m^2/day for the average transmissibility values. This range of

values is also presented in the table (printed bold).

Table 5.6 Transmissibility as a function of aquifer depth and effective porosity.

D p	100 m	300 m	500 m	700 m
0.100	4	**15**	**24**	28
0.075	3	**11**	**18**	**21**
0.050	2	6	**10**	**14**
0.025	1	3	5	7

Estimates of the thickness of the lava flows range from 100 to 1000 m and figures of 300-500 m seem plausible. More difficult is the estimation of effective porosity (available flow section). In a succession of lava flows of 300 m thickness, with a series of old land surfaces, the porosity could easily be 0.04, excluding the secondary porosity caused by the extensive fractures in the flows, which could range from 1 to >5%. Adding the secondary porosity, the overall values could range between 5 and 7.5% from which transmissibility values are inferred of 10-18 m^2/day for a groundwater age of 4,000 years (see Table 5.6). These transmissibility values are of the same order of magnitude as found in the pumping tests.

The above discussion is based on very general estimates only but is able to show consistent relationships between inferred values for groundwater age, aquifer properties and recharge. In order to give more exact figures a detailed study of Laikipia's aquifer system is necessary on a scale beyond the scope of this assessment study.

5.5.5 Chemical Composition of Groundwater

The results of chemical analyses of water samples collected from 33 boreholes before the WRAP activities started in Laikipia are listed in Table 5.2. From these results, the W.H.O - recommended maximum permissible limit of 1,500 mg/l of TDS for drinking water is exceeded in 3 cases (11%) while the W.H.O - recommended fluoride content limit of 1.5 mg/l in drinking water is exceeded in 19 cases out of 26 (73%). High salinity values are given by water samples from boreholes C2676 (7,550 mg/l) C2889 (6,150 mg/l) within the Lower Ewaso Narok Phonolites and from borehole C2803 (5,550 mg/l) which is sunk in the Mount Kenya Volcanic Series. High fluoride content is found in groundwater within the Lower Ewaso Narok Phonolites (31%), the Marmanet Phonolites (12%), the Sipili Trachytes (4%), the Mount Kenya Volcanic Series (19%) and the Olivine Basalts (8%). The general conclusion would have to be that the use of groundwater resources might be limited due to high fluoride content.

To confirm the above results, the project collected 24 more water samples for chemical analyses. Where possible some of the boreholes (in which F and salinity is high) shown in Table 5.2 were resampled, and where it was impossible due to non-operation of the borehole an attempt was made to sample the nearest operating borehole. The results of these chemical analyses are listed in Tables 5.3. (boreholes) and 5.4 (springs).

Table 5.7 **Interpretation of Chemical Data Analyses**

Name of Spring/B.H. No.	meq/l							Difference (%) between Sums of the Cations & Anions	Aquifer System
	Na+K	Ca	Mg	Cl	HCO_3	SO_4	Sum of reacting values		
South Aiyam	2.97	0.02	0.67	0.34	3.28	0.04			1
Il Pinguin	8.39	0.01	0.01	2.23	5.12	0.58	16.34	2.94	1
Bakuli	1.73	2.40	1.67	1.61	3.90	0.29			1
Kiabogo Mastoi	2.67	1.25	1.50	1.55	3.08	0.79			1
Large Scale	0.15	0.01	0.79	0.17	0.75	0.03			1
Tandare	1.99	0.75	1.00	0.54	3.18	0.02			1
Njonjo Girls	0	0.34	0.67	0.14	0.69	0.03	1.87	8.02	1
Marmanet	1.38	0.4	0.92	0.48	2.20	0.02			1
Kwa Nugu	0.28	0.18	0.51	0.11	0.85	0.01			1
Muruku	1.32	0.60	1.67	0.37	3.21	0.01			1
Bustani	3.78	0.28	0.61	1.89	2.72	0.06			1
Ngusishi	0.03	0.60	0.18	0.11	0.69	0.01			1
Ngarua	2.63	0.28	0.48	0.65	0.65	2.59			1
Shauri	0.60	0.4	0.41	0.28	1.05	0.08			1
Shereta	3.68	0.48	0.61	0.59	4.00	4.00			1
Kandoro	0.69	0.65	0.77	0.59	1.31	0.21			1
Wellmount	0.55	0.28	0.37	0.17	0.98	0.05			1
Mutanga	1.66	0.28	0.33	0.54	1.54	0.19			1
Reuben	0.19	0.60	0.44	0.14	1.08	0.01			1
Sukuta Marmar	5.78	0.06	0.03	1.18	4.33	0.50	11.88	1.16	1
Sukuta Mugie	5.37	0.13	0.03	0.82	4.52	0.18	11.05	0.10	1
Sukuta Naibor	5.81	0.09	0.04	0.87	4.62	0.15	11.58	2.59	1
Mbugua	0.10	0.08	0.44	0.25	0.33	0.04			1
Kirimuni	6.80	0.23	0.16	1.94	4.10	0.42	13.65	5.35	1
C45	1.72	1.00	1.00	0.31	3.34	3.34	0.07		1
C66	1.02	0.60	1.67	1.27	1.80	0.22			1
C150	4.46	0.68	1.29	1.35	4.89	0.19			1
P152	4.36	1.45	0.92	0.85	5.57	0.31			1
C296	5.91	1.40	1.83	2.14	6.23	0.77			1
C297	5.16	1.40	1.25	1.35	6.13	0.33			1
C309	1.66	0.32	0.81	1.38	6.95	0.46			1
C337	2.86	1.25	0.89	0.51	4.26	0.23			1
C342	7.29	0.003	0.14	1.07	5.34	0.39	14.233	14.44	1
C372	7.20	3.75	3.00	0.93	5.02	1.25			2
C373	3.32	2.10	1.25	0.68	5.74	0.25			1
C523	3.63	1.10	1.50	1.18	4.82	0.23			1
C571	1.87	1.20	2.00	0.85	4.13	0.09			1
C611	6.24	0.27	0.23	0.08	3.64	0.46	12.92	4.34	1
C674	1.65	2.10	1.75	1.52	2.92	1.06			1
C690	3.53	1.80	1.42	0.82	5.64	0.29			1
C887	14.37	0.08	0.22	3.35	9.51	1.04	28.57	2.69	1
C912	5.64	0.12	0.08	0.31	5.41	0.12			1

Cont. **Table 5.7 Interpretation of Chemical Data Analyses**

Name of Spring/B.H. No.	meq/l Na+K	Ca	Mg	Cl	HCO_3	SO_4	Sum of reacting values	Difference (%) between Sums of the Cations & anions	Aquifer System
C932	4.05	1.05	1.23	0.93	4.98	0.42			1
C1224	0.92	0.36	0.65	0.62	1.08	0.23			1
C1230	1.17	3.55	2.25	1.55	4.59	0.83			2
C1381	4.82	1.10	1.00	1.30	5.18	0.44			1
C1498	3.70	3.30	2.58	1.49	1.34	6.75			2
C1646	6.09	0.30	0.21	0.99	3.15	0.23	10.97	20.31	1
C1702	7.70	0.60	0.73	1.86	6.59	0.58			1
C1767	5.01	0.88	1.33	0.23	6.16	0.83			1
C1786	7.20	0.01	0.01	0.76	4.53	0.16	12.67	13.98	1
C1819	16.42	0.06	0.01	9.13	3.28	3.46	32.36	1.92	1
C1896	11.49	0.05	0.03	3.32	3.44	2.46	20.79	11.30	1
C2023	2.00	1.15	1.50	0.39	3.12	0.03			1
C2135	4.38	6.00	3.08	1.86	4.95	6.65			1
C2259	6.97	0.03	0.02	1.66	4.23	0.42	13.33	5.34	1
C2315	4.15	0.13	0.16	0.68	3.64	0.15	8.91	0.32	1
C2318	11.97	3.40	1.50	5.63	7.25	1.77	31.52	7.05	1
C2369	2.16	0.80	1.25	0.42	3.71	0.08			1
C2381	2.10	0.48	0.92	0.23	3.25	0.02			1
C2400	7.93	0.25	0.12	0.96	4.85	0.23	14.34	15.76	1
C2594	5.87	1.50	0.92	1.72	5.90	0.67			1
C2676	9.39	0.70	0.69	2.68	3.54	1.44	18.44	16.92	1
C2727	7.98	0.08	0.01	1.35	5.67	0.41	15.50	4.3	1
C2805	7.95	0.05	0.02	2.23	4.75	0.67	15.67	2.36	1
C2858	2.78	0.42	0.22	0.34	2.52	0.04	6.32	8.24	1
C2889	8.67	0.22	0.16	1.49	6.03	0.48	17.05	6.15	1
C3420	1.36	4.45	4.92	3.07	4.10	3.56			2
C4180	0.86	0.56	0.48	0.51	1.34	0.05			1
C4683	3.52	1.55	1.42	0.90	3.84	1.75			1
C5069	1.86	0.24	0.44	1.27	1.25	0.02			1
C5140	4.08	8.15	5.83	4.82	7.51	1.25	31.64	14.17	2
C5197	5.49	3.45	3.25	4.25	4.16	1.46	22.06	10.51	2
Mwenje well	3.37	0.77	3.38	1.31	0.10				

According to the new results the W.H.O - Recommended maximum permissible limit of 1,500 mg/l of TDS for drinking water is not exceeded. But the TDS within the upper limit (over 1,000 mg/l) is found in 2 boreholes C887 in Solio Ranch and C1819 in Ol Maisor Ranch, North of Rumuruti. The maximum TDS in C1819 is 1,176 mg/l. The bicarbonate is the major anion (Figure 5.3). And groundwater in Laikipia District is mainly of the type Na + K-HCO_3. But Na + K-Cl water is found in borehole C1819.

It should be noted that for the presentation of Stiff diagrams (Fig. 5.3) Na and K had to be calculated (Table 5.7) since in most of the samples this anion was not determined. It can be seen that in 12 cases of complete

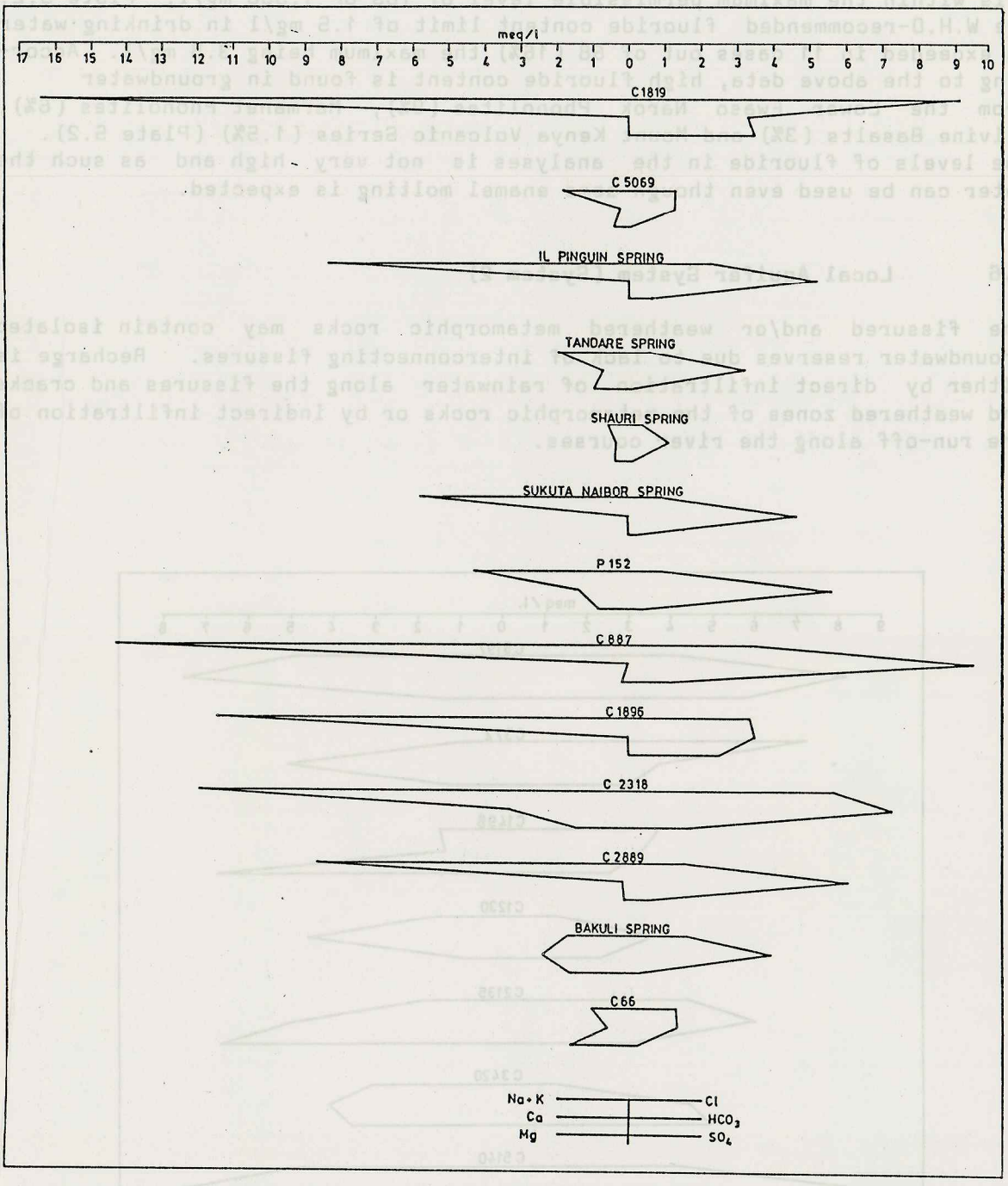


Figure 5.3 Stiff Diagrams of Groundwater Samples from System 1

chemical analyses out of 22 (55%) the results of the analyses are not good since the difference in percentage of the reacting values (anions and cations) exceed 6% (Table 5.7).

According to the W.H.O. standards for drinking water, groundwater in system 1 is within the maximum permissible level of TDS OF 1,500 mg/l, Plate 5.2. The W.H.O-recommended fluoride content limit of 1.5 mg/l in drinking water is exceeded in 11 cases out of 68 (16%) the maximum being 3.8 mg/l. According to the above data, high fluoride content is found in groundwater from the Lower Ewaso Narok Phonolites (9%), Marmanet Phonolites (6%), Olivine Basalts (3%) and Mount Kenya Volcanic Series (1.5%) (Plate 5.2). The levels of fluoride in the analyses is not very high and as such the water can be used even though some enamel molting is expected.

5.6 Local Aquifer System (System 2)

The fissured and/or weathered metamorphic rocks may contain isolated groundwater reserves due to lack of interconnecting fissures. Recharge is either by direct infiltration of rainwater along the fissures and cracks and weathered zones of the metamorphic rocks or by indirect infiltration of the run-off along the river courses.

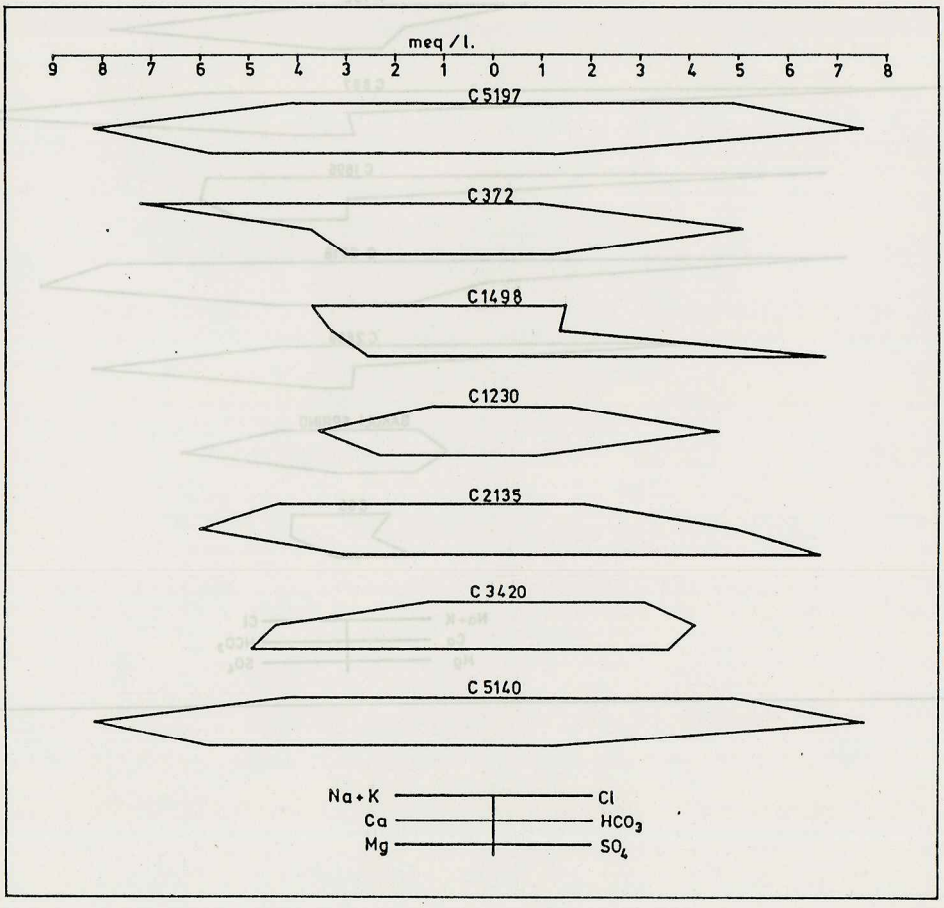


Figure 5.4 Stiff Diagrams of Groundwater Samples from System 2

5.6.1 Transmissibility, Specific Capacity and Yield

Data from only one borehole (C5360) was used for the calculation of two hydrogeological parameters, namely: transmissibility and specific capacity.

The two parameters are of the same magnitude transmissibility being 5.2 m^2/day while specific capacity is 5.5 m^2/day, indicating good well completion. The borehole yield is 2.3 m^3/h at a drawndown of 10 metres.

5.6.2 Groundwater Levels

A total number of 56 boreholes has been sunk in this system. The difference between the water struck and rest levels indicates that the aquifers are generally confined in a few cases where free groundwater is encountered. The confinement is probably due to the weathering of the gneisses into clayey material which forms an impervious layer above the aquifer.

Groundwater is encountered between 20 and 142 metres and water rest levels vary from 6 to 49 metres below ground level (Plate 5.2).

5.6.3 Chemical Composition of Groundwater

The chemical analyses results of the water samples taken before 1984 are listed in Table 5.2. The W.H.O-recommended maximum permissible limit of 1,500 mg/l in drinking water is not exceeded. The W.H.O-recommended fluoride content of 1.5 mg/l is exceeded in one case out of 6 (16.67%). Out of 7 water samples collected by WRAP the W.H.O -recommended limit of 1,500 mg/l is also not exceeded, the maximum being 660 mg/l. And the W.H.O-recommended fluoride limit 1.5 mg/l is exceeded in one case (14%), the maximum being 2.6 mg/l.

Groundwater in system 2 is mainly of Ca Mg - HCO_3 type, but in boreholes C1498 and C2135 the water is of the Na - SO_4 and Ca - SO_4 type respectively (Figure 5.4).

With the exception of groundwater from borehole C372 whose fluoride content exceeds the limit of 1.5 mg/l, groundwater in system 2 is good for drinking purposes.

The W.H.O. - recommended fluoride content limit of 1.5 mg/l in drinking water is exceeded in one case: borehole C23.

6. WATER RESOURCES ASSESSMENT

6.1 Previous Studies

In 1963 the Ministry of Works 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 the ranching, mixed farming and semi-arid areas. It will also be seen that the natural river flows must be controlled if the water is to be made available where and when it is needed, and that the present method of apportionment allows very high water losses in the lower catchment below Archer's Post".

The report recommended that "a much greater use should be made of sub-surface water for stock and domestic supplies, particularly in the lower catchment, and that when the necessary boreholes have been proved or alternatively, pipelines put into operation, the minimum flow at Archer's Post should be maintained at 10 cusecs instead of 42 1/2 cusecs as heretofore. This will mean that more dry-season flow will be available for use where there is a potential of good irrigable land. It will also be necessary to construct dams in the upper catchment to regulate river flows and conserve flood waters for use in the dry season when irrigation needs are greatest".

In 1964, Bristow concluded that "In the south-western part of the area (=Central Laikipia) many times more boreholes than there are at present can be drilled before any depletion is likely to occur" and that "it is not possible to give any indication at all as to how many more boreholes than there are at present can be drilled in these lower rainfall parts of the area, but it is also probably considerable".

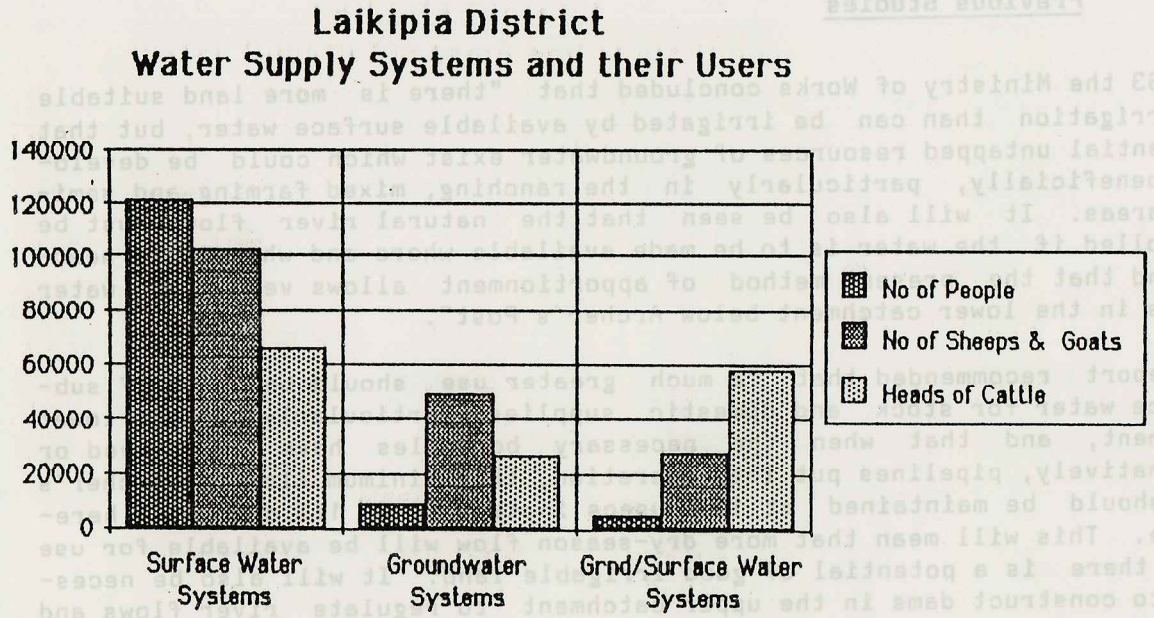
The 1983 ASAL report on Laikipia District repeats most of the conclusions from the above mentioned reports. In addition, it adds that the flow regime cannot sustain further exploitation. Its main recommendations are that:

- a water resources assessment be undertaken
- illegal abstractions of streamflow be controlled
- a computerized database be established
- construction of large dams and drainage of the swamps be investigated.

6.2 Water Supplies

A water survey covering approximately 90% of the district was held in 1986 during which 86 water supplies were visited. Details of this survey are listed in Appendix 6.1. In addition a water permit inventory was carried out in the beginning of 1987 in order to obtain information on the legal surface water abstractions.

The most important water supplies in Laikipia District are mainly based on surface water (Figure 6.1). Nearly ninety percent of the people depends on such systems. Other types of water supplies are based on boreholes, springs, wells, dams and rock catchments, or a combination of these. Surface water permits are issued for 621 different abstraction points along



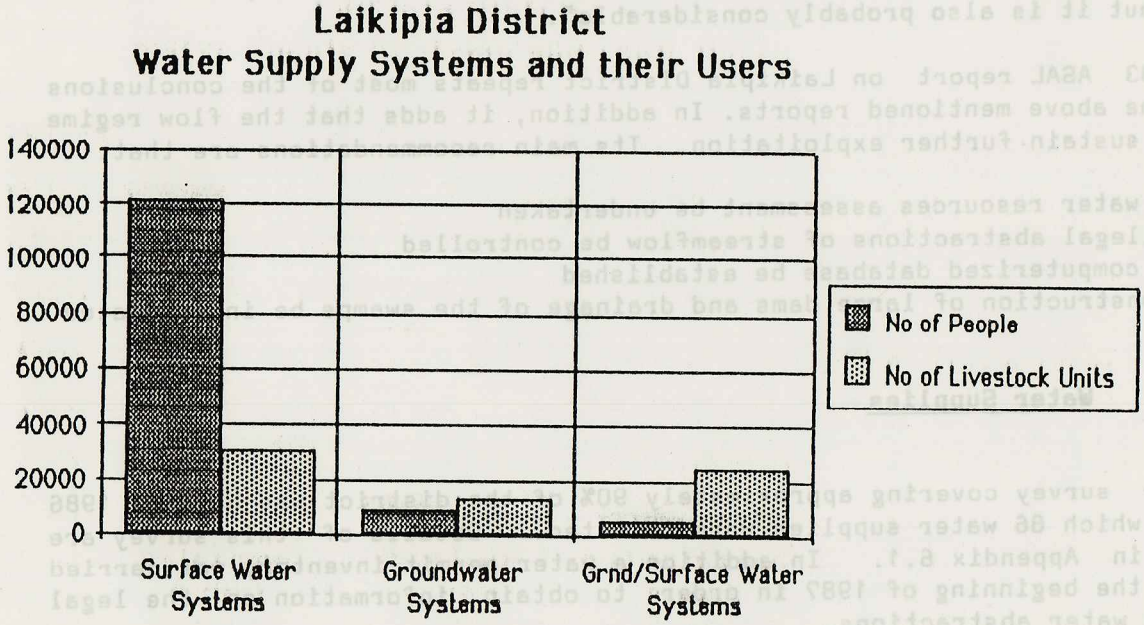


Figure 6.1 Water Supply System and their users

the rivers in drainage areas 5A,B,C and D endorsing a total surface water abstraction upstream of the Junction of the Ewaso Narok and the Ewaso Ng'iro of 1.36 cumec for normal flow conditions and 3.84 cumec for flood flow conditions. This is more than 3 times the permitted abstractions for normal flow in the early sixties which was only 0.396 cumec (Ministry of Works, 1963). The flood flow figure for this time is not precisely known but was probably around 1.3 cumec. A breakdown of the permitted abstractions is given in Section 6.4.1.

Other types of water sources are boreholes, wells, springs, dams and rock catchments. There are 120 operating boreholes, mainly in the ranches which supply water for both domestic and livestock uses. The operating boreholes are concentrated in Central Division, that is between Nanyuki Town and Pesi Swamp. Furthermore, water is also obtained from springs in Central, Rumuruti and Ng'arua Divisions. In Mukogodo division it is obtained from hand-dug wells in the river beds during the dry seasons.

A few statistics on the number of people and cattle served by these water supply systems are given in Table 6.1 and Figure 6.1. Note that the population number does not agree very well with the number of people living in the district according to the census (Table 1.2).

Table 6.1 Water Supply Systems in Laikipia District

	Surface Water Systems	Groundwater Systems	Mixed Systems	Total
No of People	89%	7%	4%	136,950
Sheep & Goats	57%	28%	15%	180,470
Heads of Cattle	44%	18%	38%	152,103

The supplies under construction and proposed are listed in Table 6.2

6.3 Water Demand

6.3.1 Domestic Demand

The average domestic daily water demand for Laikipia District was estimated by assuming a per capita consumption as described in the Design Manual of the Ministry of Water Development from 1979.

This manual specifies the water demand for rural areas as follows:

- 25 litres per capita per day when served by communal water points
- 50 litres per capita per day when served by individual connection
- 75 litres per day per livestock unit (LSU). Such a unit consists of 2.5 cows, 20 goats or sheep, or 1.25 camels.

Table 1.2 in Chapter 1 contains estimates of the divisional populations in Laikipia District for the year 1988 while livestock data are presented in

Table 1.3 (Chapter 1). Using these data, Table 6.2 presents the water demand estimates for 1988 and 2000 using the following assumptions.

- demand as specified by the afore mentioned Design Manual.
- the percentage of individual connections is assumed to be 21% in Central Division, 3.1% in Rumuruti Division, 4.5% in Mukogodo Division and 5.4% in Ng'arua Division.
- the areal distribution of livestock to be uniform (Kremu, 1978)

Table 6.2 Water Supplies under Construction and Proposed in Laikipia District

Name	Division	Sources	Population to be Served People	Cattle	Supply
1. Under Construction					
Nyahururu Scheme	Rumuruti	Equator	8,400	2,500	
Laikipia West	Rumuruti	Muthengera Dam	30,000	-	Gravity
Ndurumo/Minjore	Rumuruti	C2574&C3761	13,200	-	Pumped
Mutaro	Central	Ngobit	1,000	700	Pumped
Wiyumiririe	Central	Ngobit	6,500	-	Gravity
Sirimon	Central	Sirimon	10,000	-	Gravity
Nyakairu	Central	Outulili	8,000	-	Pumped
2. Proposed					
Endarasha	Central	Kamigogod	13,000	-	Pumped
Oldaiga	Central	Ontulili & Sirimon	20,000	8,000	Gravity

Table 6.3 Water Demand from Households and Livestock in 1988 and 2000

DIVISION		DEMAND IN 1988				DEMAND IN 2000			
Name	Area	Demand per Capita - LSU				Demand per Capita-LSU			
		25 l/d	50 l/d	75 l/d	Total	25 l/d	50 l/d	75 l/d	Total
	Km^2	Mm^3/year				Mm^3/year			
Central	3,161	0.50	0.25	0.78	1.53	0.82	0.43	1.53	2.78
Rumuruti	3,514	0.73	0.09	0.87	1.69	1.21	0.78	1.70	3.69
Mukogodo	1,205	0.17	0.02	0.30	0.49	0.29	0.03	0.58	0.90
Ng'arua	1,098	0.51	0.06	0.27	0.84	0.86	0.10	0.53	1.49
Total	8,978	1.91	0.42	2.22	4.55	3.18	1.34	4.34	8.86

Evaluation of Table 6.1 in terms of water demand using the method of the Design Manual suggests that currently 70% of the water demand is satisfied by surface water, about 20% by groundwater and 10% by other sources such as springs and dams. Scope for meeting water demand by increasing surface water abstractions is very limited as is further development of other sources. Groundwater is still underdeveloped. Moreover, groundwater is much safer than surface water. Therefore the share of groundwater for domestic purposes and livestock should be increased. A preliminary goal of 50% should be set for the year 2000 increasing the demand for groundwater to approximately 4.5 Mm^3/year.

6.3.2 Irrigation Demand

During dry seasons, water is the limiting factor for agriculture as soils are generally very fertile: many crops could be grown during the dry season if it were not for lack of water. Thus, during the dry months from January to March, potential water demand for irrigation is high, much higher than can ever be satisfied by the baseflow of the perennial rivers. Due to the high prices, irrigated horticulture in the dry season is a profitable affair and the temptation to illegally divert river water for irrigation difficult to resist. However, reliable estimates on the magnitude of illegal diversions do not exist.

6.4 Water Resources Availability

6.4.1 General

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

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

Water requirements vary with its intended use. The studies carried out by WRAP consider mainly domestic use, stock watering and small scale irrigation.

6.4.2 Surface Water

- Source Areas

The Middle and Upper Volcanic Slopes of Mount Kenya and the Aberdares are the most productive areas for runoff generation. Here, rainfall is high and rather evenly distributed over the seasons. Infiltration condition are favourable due to the forest cover and the soils. The volcanic rocks near the eruption centres generally are good aquifers: ash covers are usually course grained while cinder layers between lava flows can be very permeable. Groundwater and soil moisture emerges in many springs and seepages, thus becoming baseflow. On Mount Kenya small springs are common whereas more large springs are present in the Aberdares range.

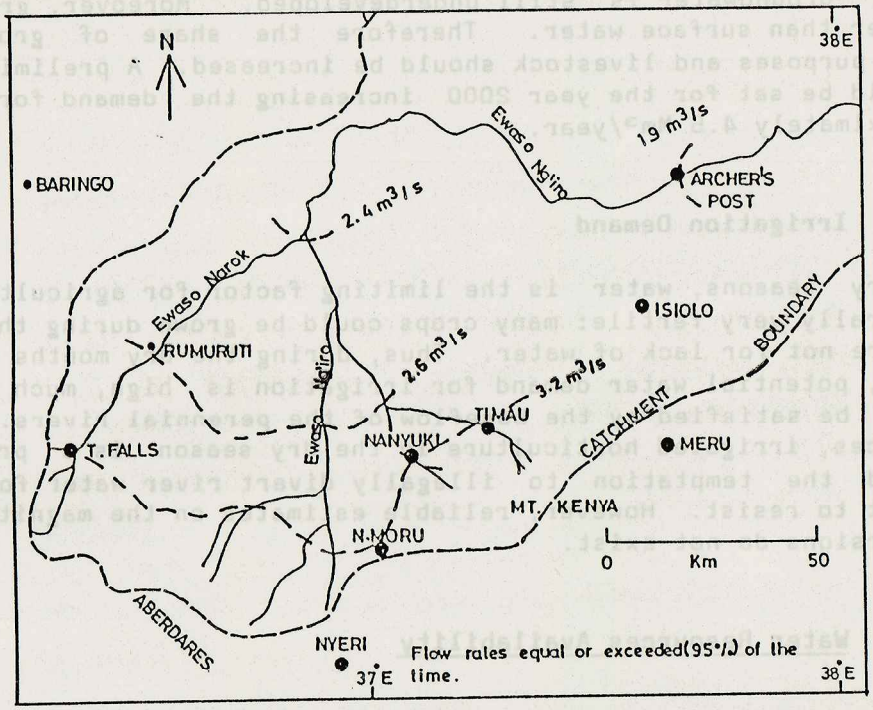


Figure 6.2 Total Available streamflow (95%) including Abstractions

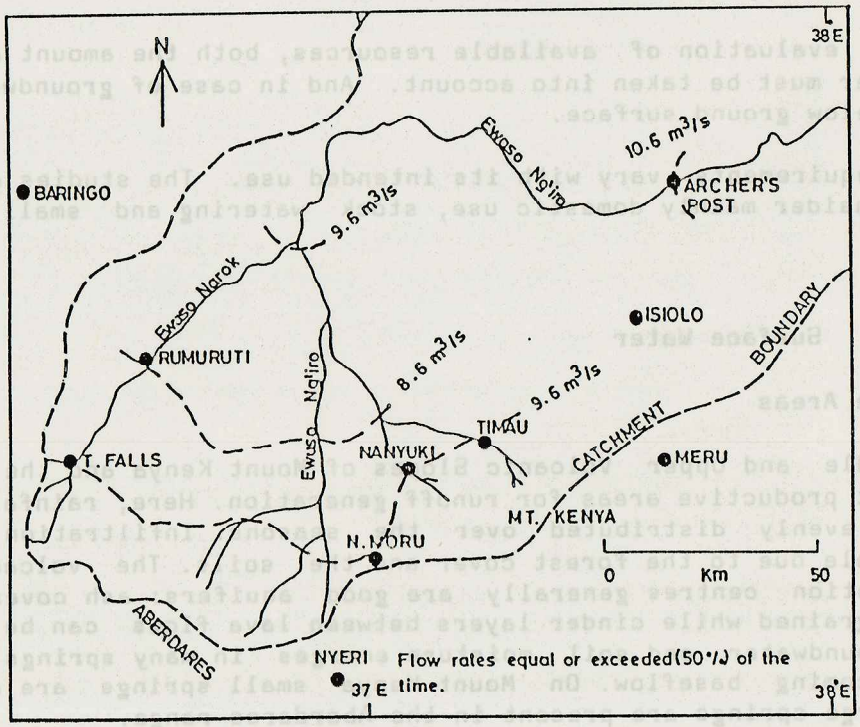


Figure 6.3 Total Available streamflow (50%) including Abstractions

Elsewhere, runoff production is lower and more variable in time. In a downstream direction from the boundary between the Middle and Lower Volcanic Slopes, springs become increasingly rare due to the deep water table. Runoff production in these areas becomes increasingly confined to rainy periods.

Table 6.4 summarizes the relative contribution of sub-areas for a respectively dry, average and wet year. Note the strong variability of runoff production in the lowest part, the Basement area below the Junction. In dry years, most water comes from the Ewaso Ngiro system which comprises large parts of Mount Kenya and the Aberdares: most baseflow originates in these areas. But in wet years, the Basement Area below the Junction is the major source of streamflow at Archer's Post.

- Mean Flow and Seasonal Variations

The annual and monthly means of streamflow at the Junction and at Archer's Post are shown in Figure 6.2.

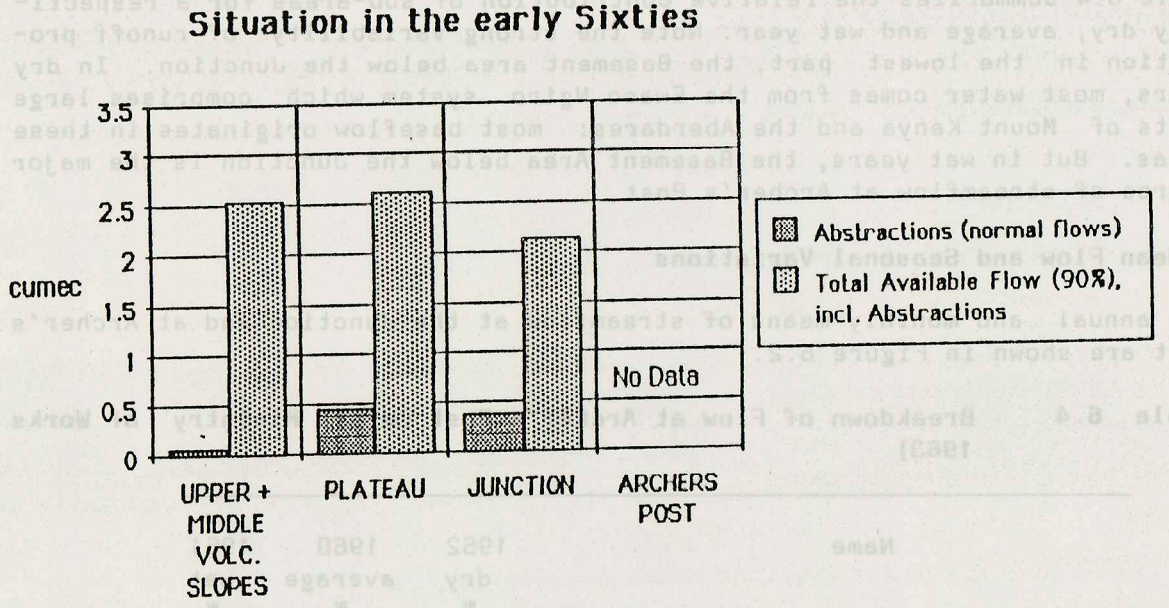
Table 6.4 Breakdown of Flow at Archer's Post (after Ministry of Works 1963)

Name		1952 dry %	1960 average %	1951 wet %
Upper Basin (Above the Junction)	{ Ewaso Ng'iro	75	67	22
	{ Ewaso Narok	18	11	22
Middle Basin	{ From the Junction to Archer's Post	7	22	56

Table 6.5 Average Streamflow at the Junction and Archer's Post.

River	Location	Station	Area km2	Average Discharge cumec	mm/year
Ewaso Narok	Junction	5AC8	3294	3.84	36.8
Ewaso Ngiro	Junction	5D5	4561	8.60	59.5
Ewaso Ngiro	Archer's Post	5E3	15300	27.2	56.1

According to these data, the average flow of the Ewaso Narok is only 45% of the average flow of the Ewaso Ngiro while the total streamflow at the Junction amounts to 46% of the runoff at Archer's Post. This also demonstrates that run-off generation in the semi-arid Basement Area downstream of Archer's Post is substantial, although most of it is surface run-off. It must be kept in mind though that the accuracy of the runoff estimated at the Junction is not as high as at Archer's Post where the observation frequency is much higher and the changes of water levels more gradual. In addition, at the Junction where time-lag is short, floods pass during the



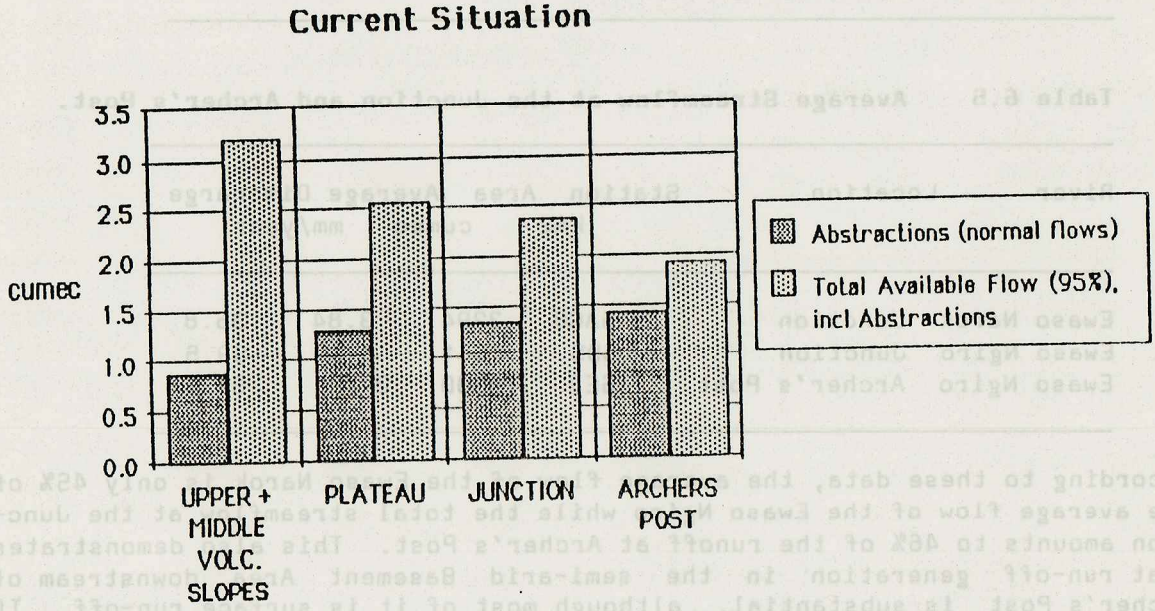


Figure 6.4 Streamflow and Abstractions

night during which staff gauges are not read while at Archer's Post floods tend to pass during the late night and morning.

The seasonal variations of streamflow of both rivers at the Junction are fundamentally different. The hydrography of the Ewaso Ngiro river is double peaked reflecting both the short and long rains. The hydrography of the Ewaso Narok though is triple peaked with maxima in January, April and August. The April and August peaks reflect the long and continental rains respectively. The short rains do not appear.

- Available Streamflow

The current dry and wet season surface water availability is presented in Tables 6.6 and 6.7. Table 6.6, the dry season table, contains current estimates on the 95% streamflows and the legal normal flow abstractions. In addition it presents data on total available 90% streamflows and normal flow abstractions from the early sixties. For details on the situation in the early sixties reference is made to the MOW, 1962. Table 6.7 presents the situation during the rainy season, and shows estimates on the 50% stream flows and the flood flow abstractions.

The notions 50%, 90% and 95% streamflows refer to discharges which are exceeded during respectively one in two, ten and 20 days. The 50% streamflow is considered to be the minimum discharge during rainy seasons while the 90 and 95% flows are fair approximations of drought flow. Substantially lower discharges occur only during extreme droughts as the one in 1984/5. The 95% flow has been taken because this value is often used for the design of irrigation schemes. Many of the frequency curves used to estimate the flows are presented in Appendix 4. Values of stations for which frequency analysis was not available are marked with an asteria.

The flow estimates are divided into four groups according to geographical location of the stations:

(i) the stations draining the Volcanic Slopes,
(ii) those situated on the Central Plateau,
(iii) those at the Junction and
(iv) Archers' Post.

Lines which interconnect the locations of the groups of stations are depicted in Figure 6.2 and 6.3.

Note that the estimates on available drought flows, being the sum of abstractions and actual streamflow, decrease gradually in a downstream direction. The explanation for this phenomenon is:

(i) that most baseflow originates on the higher parts of the catchment and that part of it infiltrates into the river beds and the swamps along the lower reaches, and
(ii) that the sum of the illegal abstractions increases in a downstream direction.

The total available rainy season streamflows with probability levels of 50% are rather constant along all four cross-sections. The accuracy of these estimates is probably quite acceptable as:

(i) at most stations actual discharge measurements are still avail-

Table 6.6 Dry season surface water resources

		VOLCANIC SLOPES				PLATEAU				JUNCTION				ARCHER'S POST			
AREA	RIVER	RGS	Upstream Abstractions cumec	Stream Flow 5% prob cumec		RGS	Upstream Abstractions cumec	Stream Flow 5% prob cumec	Available Flow incl.abstr cumec	RGS	Upstream Abstractions cumec	Stream Flow 5% prob cumec	Available Flow incl.abstr cumec	RGS	Upstream Abstractions cumec	Stream Flow 5% prob cumec	Available Flow incl.abstr cumec
EWASO NAROK BASIN	E.Narok	5AA1	0.1860	0.520		5AC11	0.195	0.500	* 0.695								
	Pesi	5AB3	0.5880	0.200		5AB2	0.591	0.150	0.741	5AC8	0.831	0.200	1.031				
	Mutara	5AD1		0.050	*	5AD3	0.000	0.000									
NORTHERN ABERDARES	Suguroi	5BD2		0.000					0.000								
	Ngobit	5BC8	0.0014	0.150	*				0.151								
	E.Ngiro	5BB2	0.0070	0.300	*				0.307								
MOUNT KENYA (western slopes)	Moyo	5BA1				5BC4	0.375	0.300	0.675					5E3	1.430	0.500	1.930
	Naro Moro	5BC2	0.0223	0.200	*				0.222								
	Rongai	5BC5	0.0004	0.015					0.015								
	Burguret	5BC6	0.0017	0.130					0.132								
										5D5	0.533	0.800	1.333				
MOUNT KENYA (north-western slopes, Nanyuki river system)	Nanyuki	5BE1	0.0099	0.100	*				0.110								
	Ontulili	5BE2	0.0366	0.070	*				0.107								
	Kongoni	5BE3	0.0002	0.003	*				0.003								
	Sirimon	5BE4	0.0010	0.090	*				0.091								
	Teleswani	5BE5	0.0119	0.120	*	5BE20	0.141	0.300	0.441								
	Timau	5BE6	0.0134	0.100	*				0.113								
	Liki	5BE7	0.0070	0.220	*				0.227								
	Ngusishi	5BE19		0.050	*				0.050								
											flow estimates without * are based on the 1976-85 duration lines flow estimates followed by * are based on other data							
TOTAL			0.8870	2.318			1.302	1.250	2.552		1.364	1.000	2.364		1.430	0.500	1.930
TOTAL	(early sixties)		0.0860	2.515			0.474	2.142	2.616		0.396	2.150	2.150				

able for these flow rates and

(ii) that illegal abstractions during rainy seasons are probably lower than during dry periods

The totals for the dry seasons have been depicted in Figure 6.4. Striking is the change since the early sixties. Surface water abstractions have gone up so much that current levels are close to total available flows at Archers Post. Taking into account that only legal abstractions are considered, it is no wonder that the Ewaso Ngiro upstream of Archers' Post fell dry for several weeks at the end of the driest period on record in 1984/5. Flows did not recover fully in the following year: the river dried up again in the beginning of 1986 before the long rains. In fact, given the present situation, it can be expected that the drying up of the Ewaso Ngiro in a river reach of about 50 km length or more upstream of Archers Post will become a normal phenomenon if the situation is not reversed. Action, notably to curb illegal abstractions is required.

Fortunately the situation during rainy seasons is not yet that serious. In this time, enough water is still available.

6.4.3 Groundwater

The total amount of groundwater which is annually replenished has been estimated to be in the range of 120 to 220 Mm^3 (Chapter 5). But the amount of water which can be abstracted is considerably lower. A large part of the infiltrating rain either penetrates to great depth or emerges in springs or seepage zones, often in river beds. But even if the recoverable amount of groundwater were only 5% of the recharge, the estimated present and future groundwater demand in Laikipia (0.9 and 4.5 Mm^3) can be met.

However, groundwater is unevenly distributed over the area. In the Volcanic Slopes above 2,000 m, where humid and semi-humid conditions prevail, there is plenty of groundwater. But here it is least needed. In the plains of Central Laikipia enough groundwater is available for domestic use and stock watering. Site selection is not critical as virtually all boreholes were successful although sometimes it is necessary to drill to a depth of more than 200 meters before water is encountered. But locally, shortages may occur in the Basement area where major parts are not underlain by aquifers.

Strong variations in water quality also contribute to the uneven distribution of suitable groundwater: quality of 16% of the sampled boreholes made its water unsuitable for domestic purposes, mainly due to high fluoride.

A groundwater availability map is prepared and shown as Plate 6.2. On this map, six different groundwater regions have been distinguished which have been subdivided into 4 classes: (i) High potential, (ii) High-to-Medium Potential, (iii) Medium Potential, (iv) Low Potential and (v) Variable Potential.

Table 6.7 Rainy season surface water resources

AREA	RIVER	VOLCANIC SLOPES RGS	Upstream Abstractions cumec	Stream Flow 5% prob cumec	Available Flow incl.abstr cumec	PLATEAU RGS	Upstream Abstractions cumec	Stream Flow 5% prob cumec	Available Flow incl.abstr cumec	JUNCTION RGS	Upstream Abstractions cumec	Stream Flow 5% prob cumec	Available Flow incl.abstr cumec	ARCHER'S POST RGS	Upstream Abstractions cumec	Stream Flow 5% prob cumec	Available Flow incl.abstr cumec
EWASO NAROK BASIN	E.Narok	5AA1	0.2510	1.050	1.301	5AC11	0.304	1.000 *	1.304								
	Pesi	5AB3	0.5940	0.400	0.994	5AB2	0.663	0.350	1.013	5AC8	1.153	0.800	1.953				
	Mutara	5AD1		0.010 *	0.010												
NORTHERN ABERDARES	Suguroi	5BD2		0.100	0.100												
	Ngobit	5BC8	0.0755	1.200 *	1.276												
	E.Ngiro	5BB2	0.0281	1.000 *	1.028												
						5BC4	1.000	2.000	3.000					5E3	4.080	6.500	10.580
MOUNT KENYA (western slopes)	Moyo	5BA1															
	Naro Moro	5BC2	0.0878	0.800 *	0.888												
	Rongai	5BC5	0.0010	0.500	0.501					5D5	2.690	5.000	7.690				
	Burguret	5BC6	0.0246	0.100 *	0.125												
MOUNT KENYA (north-western slopes, Nanyuki river system)	Nanyuki	5BE1	0.0521	0.500 *	0.552												
	Ontulili	5BE2	0.0859	1.000 *	1.086												
	Kongoni	5BE3	0.0056	0.500 *	0.506												
	Sirimon	5BE4	0.0173	0.050 *	0.067	5BE20	0.801	2.500 *	3.301								
	Teleswani	5BE5	0.0223	0.500 *	0.522												
	Timau	5BE6	0.0313	0.200 *	0.231												
	Liki	5BE7	0.1590	0.200 *	0.359												
	Ngusishi	5BE19		0.010 *	0.010												
GRAND TOTAL			1.4360	8.120	9.556		2.768	5.850	8.618		3.843	9.643	9.643		4.080	6.500	10.580

flow estimates without * are based on the 1976-85 duration lines
flow estimates followed by * are based on other data

I. High Potential

- Zone 1, The Volcanic Slope Region (excluding the Thomsons Fall Phonolites)

This region encompasses the humid and semi-humid parts of Mount Kenya and the Nyandarua Range, above 2000-2500 m. Only the area east of Nyahururu underlain by Thomson's Falls Phonolites is excluded and classified as low potential. Most of it lies outside Laikipia District and has not been studied in detail.

Climate is humid to semi-humid. Recharge potential is considerably, notably during the rainy seasons when rainfall exceeds evapotranspiration for a couple of months. In addition, infiltration capacities are high due to the forest cover and the relatively coarse underlying rocks.

The Upper and Middle Volcanic Slopes are groundwater recharge areas. The Middle and, in a lesser degree the Lower Slopes are areas where groundwater emerges in large quantities in the valleys thus sustaining baseflow. The driving force behind this process is the decreasing transmissibility in downstream directions where volcanic deposits become increasingly fine and aquifers thinner. The Wellmount springs (0.35 cumec) near Nyahururu probably discharge groundwater flowing northwards in the plane of the Sattima Fault which apparently terminates as an important aquifer in their vicinity. The high grounds between the rivers are intake areas.

The main geological formations are the Laikipian Basalts and the Mount Kenya suite. The aquifers comprise old land surfaces, tuffs, faults and fractures.

Large parts of this region lack boreholes. But the available information indicates that restlevels on the Lower and Medium Slopes are shallow enough for handpumps. Restlevels are probably rather deep below the upper slopes. Borehole yields vary between 2 and 10 m^3/h.

Isotopes samples indicate that water is rather young, less than 30 years old. Water quality is usually good enough for domestic use and stock watering although locally high fluoride concentrations may occur. Irrigation is not relevant as most of the area is humid or semi-humid. Site selection is not critical as groundwater is encountered almost everywhere.

II. High-to-Medium Potential

- Zone 2, The Nanyuki-Rumuruti-Sukuta Plains and Marmanet Ridge Region

The main geological formations are the Mount Kenya Volcanic Series, the Laikipia Basalts, the Lower Uaso Narok and Marmanet Phonolites. The main aquifers are old land surface deposits, tuff, fissures and decomposed zones within the lavas. Recharge in the southern part of the region is mainly by lateral percolation from Mount Kenya and the Aberdares. Recharge in the northern part is limited as it comes from vertical percolation.

Rest levels are usually between 40 and 55 m below ground surface. The mean depth is about 45 meters but values range between 0 and 84 m. Thus, handpumps can be used in most of region to pump water from boreholes. The depth to the aquifers varies even stronger: from 0 to 204 meters. The mean tested yield is 5.7 m^3/h with a standard deviation of 3.6 m^3/h. The range

lies between 1 to 15 m^3/h.

Water quality is usually good enough for domestic purposes and cattle watering although locally high fluoride concentrations are found. Water is suitable for irrigation, but borehole yields are generally insufficient. Site selection is not critical as groundwater is encountered almost everywhere in the Region.

III. Medium Potential

- Zone 3, Lariak - Sipili Plateau Region

This is a topographic high underlain by phonolites. Aquifers are old land surfaces occurring at great depths below groundsurface. Fissures and fractures also play a role.

The average depth to the aquifers is 200 metres ranging between 140 and 270 meters depth. The average rest level is about 105 meters below ground surface due to exceptionally high hydraulic heads. Rest levels vary from 60 to 120 meters depth. Handpumps are not suitable for such great depths. Instead, pumps powered by windmills or turbine engines must be used. The mean tested yield is 7.0 m^3/h; the standard deviation 4.1 and the range 3 to 11 m^3/h.

Water quality is good enough for domestic use and irrigation.

The area has a reasonable potential but recharge is low as is evidenced by the isotope samples. They give a groundwater age of about 10.000 years. Therefore, groundwater in this region is a precious commodity and should be used for domestic purposes and cattle watering only. Site selection is not critical.

- Zone 4, Basement System Region

This area is underlain by metamorphic rocks of the Basement System. Unlike in the Volcanics, aquifers are not interconnected. Prospects for water development are favourable in the valleys, notably where deep sub-surface decay has produced thick zones of more or less permeable material. But on the high grounds, prospects are not good although locally small aquifers occur where contrasts in permeability are high.

Mean depth to water level is 31 meters. The depth ranges between 6 and 50 meters. Therefore boreholes can be equipped with handpumps. Mean depth to the aquifers is 72 meters varying from 20 to 140 meters. Average tested yield is 4.1 m^3/h. The standard deviation of 3.2 m^3/h. Values range between 0.5 and 14 m^3/h.
Water quality is generally good for domestic use although locally fluoride values up to 2 mg/l occur. Saline water may also occur locally.

The region has a medium potential for water development. Tested yields are not bad but aquifers are local and recharge is low due to the semi-arid climate. Major parts, notably the high grounds, do not contain water in recoverable quantities. But locally, notably as far down the valleys as possible, favourable conditions for groundwater exist. Borehole siting by an experienced hydrogeologist is worth the costs. Geophysical techniques could be helpful.

IV. Low Potential

- Zone 5, Thomsons Falls Phonolites Region (Nyahururu - Upper Pesi Area)

This region is underlain by the Thomson's Falls phonolites. Aquifers are generally shallow and yields are poor. Six boreholes were complete failures (Bristov et al, 1964). Prospects for water development are unfavourable.

Depth to the water rest level in the successful boreholes is less than 60 meters and the depth to the aquifers less than 100 meters. The average tested yield is 1 m^3/h.

Groundwater quality is good.

Taking into account the low yields and the number of complete failures, the potential for water development in this region is low. Borehole siting with or without geophysics is not likely to improve the success rate significantly.

V. Variable Potential

- Zone 6, The Mukutan-Ol Arabel Region, East of the Watershed

This is an intensely faulted and fractured area underlain by varies phonolites, trachytes and tuffs. It lies outside of the Ewaso Ngiro catchment: the main direction of groundwater flow is towards Lake Baringo. Information from boreholes is scarce. The central part of this region borders the medium potential Lariak-Sipili Region where aquifers are exceptionally deep while the northern and southern parts are adjacent to the high potential Region 1. The aquifers are faults, fissures, old land surfaces and unweathered tuffs.

Depth to water restlevels, depth to the aquifers and tested yield are all highly variable.

Available information on water quality indicates that water is suitable for domestic use and irrigation, but the occurrence of local spots of high fluoride concentrations along faults is likely.

Taking into account the intense faulting of the region and the heterogeneity of the rocks, potential must be very variable. Only when more information from boreholes becomes available, a more definite judgement on its potential can be given. Careful selection of drilling sites is important.

6.4.4 Surface Water Development Opportunities

It is clear that very few, if any opportunities remain for the development of projects which would require low-flow abstractions. In particular this is true for irrigation for which the peak demands for water generally coincide with periods of low-flow. Strict law enforcement by curbing illegal abstractions could alleviate the situation during droughts and thus create some room for abstractions for domestic purposes.

The medium-to-high flows constitute the main source for further development

of surface water. To meet demand when it is strongest, during droughts, building of storage facilities i.e large dams is the only solution. Each dam could service large-scale irrigation and fish production.

The MoW (1963) gives proposals for seven large dams within Laikipia. The KNMWP (1980, vol II, Chapter 8) gives a summary of reconnaissance studies for three potential dams. One location coincides with a location proposed by the MoW in 1963.

6.4.5 Groundwater Development Opportunities

- **High Potential Areas**

Most of these areas lie outside of the District on the Volcanic Slopes of Mount Kenya and the Nyandarua Range where climate is semi-humid to humid and aquifers probably better than in the plains. The greater part of these areas consists of forest reserves and it is questionable whether any development at all should be undertaken.

Water development also leads to increased use of land for agriculture with the consequent danger of erosion. In addition tourism and wildlife will be adversely affected.

- **High-to-Medium and Medium Potential Regions**

Prospects for groundwater development in this Region are favourable. At present, 120 boreholes are operational and 71 are in good condition and can be equipped with pumps without major problems. In addition, there are 23 boreholes which are blocked but can be cleaned and put into operation. Thus, the total of boreholes which are operational or easy to put into operation, is approximately 200.

To meet the foreseen groundwater demand of 4.5 Mm^3/year in the year 2000 two different options should be considered. Note that this groundwater demand amounts to 50% of the estimated total underground inflow into the area.

Option 1. Installation of Submersible pumps (turbine, electric)

In this case, it is assumed that the pumping rates are equal to the tested yield. The average tested yield is 5.5 m^3/hour. Assuming that pumpage takes place for 8 hours/day the average yield per well is 16,000 m^3/year. With the foreseen groundwater demand in the year 2000 at 4.5 Mm^3/year, about 300 boreholes should be in operation. Thus for this scenario 100 additional boreholes must be drilled to meet the anticipated groundwater demand in the year 2000.

With this pumping rate, considering the estimated recharge to the area, the boreholes should have a minimum spacing of 4 km.

Monitoring of groundwater levels is necessary if development on a large scale is going to be realised.

Option 2 Installation of handpumps

In most of the High-to-Medium Potential Area, depth-to-water rest level is less than 50 m. So, handpumps can be used. A operation schedule of 8 hours a day at a rate of 2 m^3/hour gives a yield of 16 m^3/day or about 6,000 m^3/year. In order to meet the anticipated groundwater demand in the year 2,000 of 4.5 Mm^3/year, a total of 750 boreholes must be in operation. Therefore, this scenario requires that an additional 550 must be drilled. With this pumping rate borehole spacing may be decreased to 2 km, considering the estimated recharge.

- **Low Potential Region**

Prospects to sink successful boreholes in the Low Potential Region are bad. Fortunately the areal extent of this area is limited. The use of surface water instead of groundwater is recommended.

- **Variable Potential Region**

The chances of drilling of successful boreholes is the Variable Potential Region will differ strongly from place to place. In face, this region seems to be made up of small sub areas of High, Medium and Low Potential. Surface water can be a good alternative in the humid and semi-humid parts of this region.

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