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NAIROBI, KENYA

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TNO – INSTITUTE
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PREFACE

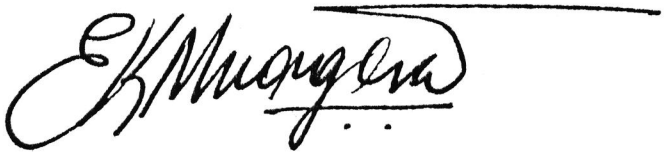
It gives me great pleasure to introduce the District Water Development Study for Samburu District.

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

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

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

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



(E. K. MWONGERA)
Director of Water Development

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ABBREVIATIONS

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

SUMMARY

The Water Resources Assessment Project (WRAP) carried out a water resources assessment study in Samburu District as part of the co-operation between the Ministry of Water Development, Nairobi and TNO-DGV Institute of Applied Geoscience, The Netherlands. This summary gives a brief account of the results of the investigations.

Project Area

The District is situated on the eastern flank of the main Kenyan Rift system. The highest elevated parts of the District include the Leroghi Plateau and the mountain ranges of Nyiru, Ndoto and Mathews (Figure 1.2). The altitude of these highlands ranges between 1,500 m and 2,500 m above sea level. The rest of the District is a continuous basin which slopes towards Lake Turkana and from Mathews Range eastward to Isiolo and Marsabit. The central plains around Baragoi and Barsaloi lie at altitudes ranging from 1,000 m to 1,350 m above sea level. The lowest parts in the District on the western and eastern boundary have an altitude of about 750 m.

The third largest river in Kenya, the Ewaso Ngiro forms the southern boundary of the District. It was a perennial river but it dried up in 1985 and 1986 for the first time in living memory because of increased abstractions in the upper reaches. Otherwise drainage is by seasonal and episodic streams (laggas), of which the main river system Seiya-Barsaloi-Milgis drains the Leroghi Plateau and the central plains of the District.

The climate is strongly associated with altitude and orientation: the highland areas and the southwestern plains receive the highest annual rainfall in the District, between 600 mm and 1,000 mm. The central basin bounded by the El-Barta and Swuari Plains and the lowlands east of the Mathews Range are the driest with an annual precipitation of between 200 mm and 500 mm.

Temperatures in the area vary with altitude and are generally between 24 °C mean minimum and 33 °C mean maximum. The central part of the District and the area east of Mathews Range exhibit the highest temperatures.

An isohyetal map showing the median rainfall (instead of the mean rainfall) is shown as Figure 3. The map is based on rainfall records where possible while extensive use was made of the vegetation where rainfall records were absent.

Surface Water Resources

Lake Turkana is by far the largest source of water in the District but it contains water of such a poor quality that it could only be used when all other supplies have dried up.

The mean annual flow of the Ewaso Ngiro at Archer's Post amounts to around 660 million m^3 with a minimum of 163 million m^3 in 1952 and a maximum of 2780 million m^3 in 1962. It was perennial but dried up in 1985 and 1986 in a reach of about 50 km upstream of Archer's Post due to increased abstractions in Laikipia District.

Virtually no data are available from the laggas in Samburu District. But data from rivers in semi-arid areas in Baringo show that streamflow could amount to an estimated 3-5%

of the rainfall. Unfortunately, the run-off is usually produced in a few days or weeks during the rainy season. So, most laggas are dry most of the time, particularly when water is most needed.

A surface water availability map based on median annual rainfalls is presented as Figure 6.1.

The area where median annual rainfall is lower than 400 mm is classified as having 'low' surface water availability. No permanent rivers rise in this area, only laggas. Dams offer little help because of low, unreliable flows combined with high evaporation. The area near Lake Turkana is also classified as such because of the poor water quality.

The area where the mean annual rainfall falls between 400 and 600 mm is classified as having 'low-to-medium' surface water availability. Perennial rivers do not originate in this area: only laggas. Nevertheless, rainfall is such that dams may keep water during normal dry seasons. But in prolonged droughts they may dry up due to high evaporation losses.

Mean annual rainfall in the mountainous zones exceeds 600 mm. This area is classified as having a medium surface water availability. A number of springs and perennial rivers originate in this zone. Dams, if properly designed, will seldom run dry.

The narrow zone bordering the Ewaso Ngiro is not classified as 'high' availability because the river has become non-permanent in recent years due to increased abstractions in the upper reaches. It has dried up along a stretch of 50 km or more upstream of Archer's Post in 1985 and 1986 for the first time in living memory. But because water is available most of the time, the stretch has been classified in the 'medium' surface water availability range.

The chemical quality of surface water of the streams in Samburu District is good.

Groundwater Resources

Enough drinking water of acceptable quality is available in most of the rural areas in Samburu: in the alluvial deposits of most laggas, shallow wells can be dug which usually strike groundwater at depths of less than 2 metres below the river bed. Furthermore, groundwater occurs in weathered or fractured Volcanic and Basement rocks, and in sediments and cinder layers interbedded between volcanic flows.
The total amount of groundwater which is annually replenished has been estimated to be in the range of 100 Mln m^3. But the amount of water which can be abstracted is considerably lower.

If a large part of the recharge would be abstracted, groundwater levels would fall and many boreholes would dry up, thus making huge investments worthless. Therefore, only a small part of the rainfall can be abstracted: safe yield can be estimated at around 20 % of the recharge from rainfall.

A preliminary estimate shows that the safe yield of about 20 million m^3/year would be more than sufficient to cover the total expected water demand of around 5 million m^3/year in the year 2013.

Groundwater availability in Samburu District (Plate 6.1) depends on the areal distribution of water-bearing zones and upon water quality. High availability areas such as defined in Laikipia and Baringo do not occur in Samburu District. The highest rating is *Medium-to-High*.

These *Medium-to-High* groundwater availability areas have a limited areal extend being the *Alluvial Deposits along the major Laggas*. Only a few of these alluvial strips are shown on the map. But it is likely that there are many more of such areas which can be found by detailed survey.

The *Leroghi and Marti Plateau* areas are classified as having *Medium* groundwater availability because (i) the boreholes have better yields than anywhere else in the District (around 4.0 m^3/h), (ii) the water quality is good and (iii) the area is underlain by extensive regional aquifers

Most of the District is classified as having *Low-to-Medium* groundwater availability. These areas are either directly underlain by the *Metamorphic Rocks of the Basement System*, or underlain by alluvial or colluvial deposits covering directly the Basement.

In the *Valleys*, groundwater availability is relatively good. Most of these valleys are underlain by alluvium or colluvium, covering soft, pelitic Basement where deep subsurface decay can produce thick zones of reasonably permeable material. This is in contrast to the mountain ranges where the dominant rock type is the more resistant massive granitoid type of Basement. The higher rainfall in these mountainous areas seems not to outweigh the adverse rock properties. Also included in this area is the extensive outcrop of Plateau Basalts in the eastern part of the District, the Marti Serteta. Its aquiferous properties are mainly determined by the underlying Basement because the thickness of the Basalt cap is usually less than 15 metres.

Mean tested yields of boreholes drawing water from alluvium or colluvium is 6.5 m^3/hour. For semi-pelitic zones it is 2.5 m^3/hour while the corresponding yields for boreholes drawing water from granitic and migmatitic zones amounts to 1.4 m^3/hour. The failure rate in the last mentioned area is about 30%. Note that it is likely that a number of dry holes were never reported to the MoWD, and that these data give a too optimistic picture.

Often, water quality is not good enough for domestic use or cattle watering, but in the absence of alternatives, the water is used by the people and their cattle. Salinity values are often too high for domestic use (ca 90%) and even for cattle watering (ca 10%). Fluoride concentrations often exceed 2.0 mg/l (ca 40%).

The *Western Strip Volcanics* were rated as having *Low* groundwater availability. This area coincides with the step-faulted zone between the Rift Valley shoulders and bottom. Groundwater levels in similar areas in Laikipia and Baringo are very deep (often more than 200 m). However, rainfall in those areas is considerably higher and groundwater levels in the Western Strip Volcanics are likely to be too deep for groundwater exploitation. Nevertheless, the hydraulic properties must be good due to the intense faulting while also the waterquality is likely to be good.

Finally, a number of isolated areas in the Basement Country were rated as having *Very Low* groundwater availability. These include the *Mountain Ranges* and the *Inselbergs* which are mainly underlain by fresh granitic or migmatitic rocks, and the small areas covered by the *Plateau Basalts*. These areas stand up as small table mountains and

it is very unlikely to strike groundwater in them in sufficient quantities for exploitation.

Surface Water Development Potential

The opportunities for water development are discussed in detail in the District Water Development Study (WRAP, 1991). Here, only broad outlines are given for a number of small-scale cost-effective water development opportunities.

The major problem in surface water development is the water distribution in time and space: most of the streams are ephemeral. So, storage facilities are required to bridge dry spells.

Along the perennial part of the Ewaso Ngiro, construction of streamflow intakes for *irrigation* can be considered. All other perennial streams have very small flows during the dry seasons. As perennial surface water supplies are very scarse elsewhere in the District, they should be used for domestic use.

In the rest of the area, *subsurface dams and sand-filled dams* built in the river beds of ephemeral streams may provide additional storage capacity (in addition the natural storage capacity of river beds).

Pans and earth dams are another important method of water development in the semi-arid parts of Kenya. Site selection is very important as the sub-soil must be impermeable to avoid seepage. Pans are primarily intended for livestock watering. The direct use of water from these sources for human consumption is not recommended because of the pollution hazards.

Roof catchments can be an important supplementary source of drinking water provided that the storage tank is properly constructed.

Application of any of these methods depends on detailed site investigations and cost analysis. This has been done in a preliminary way by the WRAP Planning section. In these reports, investment packages have been developed for the District.

Although this study concentrates on small-scale development opportunities, it must be mentioned that there are suitable sites for large dams along the gorge of the Ewaso Ngiro.

Groundwater Development Potential

Groundwater is the only permanent source of water in most of the District, and the safest source by far. So, even where abundant surface water supplies are available, groundwater from boreholes and shallow wells should be considered, particularly for domestic supplies: though development of groundwater is not cheap, the benefits in the form of the supply being permanent and reduced incidence of illnesses certainly outweigh high initial costs. Although development of a large number of permanent watering points for livestock is feasible from the resources point of view, uncontrolled development could be detrimental for the ecological balance of the District.

Medium-to-High Potential: *Alluvial Deposits along the main Laggas and underlying Bedrock.*

This area mainly consists of irregularly shaped elongated strips of alluvial deposits along the major laggas and their underlying bedrock. Its width exceeds locally 1 km. Thickness of the alluvial aquifer exceeds locally 10 m, even values of 100 m are reported. Although yields from individual wells in the alluvium are not very high (0.5 - 3.0 m^3/h, although even 7 m^3/h is reported), wells can probably be closely spaced. Recharge of the alluvial aquifers takes place twice yearly, during both the short and long rains while the underlying and adjacent bedrock is recharged from the overlying alluvium throughout the year, or until the alluvium is completely drained. During the dry seasons in between the rains, most groundwater can be abstracted from the alluvial aquifers. In contrast to elsewhere in Samburu, the alluvial aquifers along laggas can be emptied during the dry seasons: the more water is abstracted from these aquifers, the higher is the recharge during the following rainy season. The main reason to classify these areas as medium potential instead of high potential, is that the average thickness of the alluvial deposits is expected to be low, a few metres only. The chemical quality of the groundwater in the alluvium is probably the best in the District, but quality usually deteriorates rapidly when moving away from the laggas.

Traditionally, pastoralists obtained their water during dry seasons from the lagga deposits. A hole of one or two metres deep is usually enough. This source could be further developed by construction of subsurface dams and sand-filled dams in the river beds of ephemeral streams thus providing additional storage capacity (in addition to the natural storage capacity of riverbeds).

Medium Potential: *Leroghi Plateau*

This is a volcanic area with a rainfall of around 600 mm. In such aquifers, the success rate of boreholes is high while only few boreholes will have unacceptable chemical quality. Unacceptable quality is usually due to high fluoride concentrations. Borehole siting is not necessary as groundwater is nearly always struck. Despite the phonolitic nature of the aquifers, boreholes have rather high yields. Small scale irrigation (e.g. of kitchen gardens) is possible.

Low-to-Medium Potential: *Basement Area*

As aquifers in the Basement Area are isolated, it is very important to find the right sites. The aquifers can be characterized as irregularly shaped water bearing cells. Recharge often comes from laggas, or sometimes rainfall. Given the size of the Basement Area, there seems to be room for at least several hundreds of boreholes. The records suggest that almost all boreholes in alluvium/colluvium or semi-pelitic zones are successful while a success rate of approximately 70% can be expected in granitic/migmatitic rocks. Around 10% is chemically unsuitable for cattle (and humans). Groundwater development for irrigation can be ruled out because of the low yields.

Low Potential: *Western Strip Volcanics*

This area is heavily faulted and fractured. No boreholes have been drilled. Annual rainfall is low ranging between 200 and 500 mm. Similar areas in Laikipia (but with annual rainfalls of around 800 mm) were classified as having medium or variable groundwater availability. Even so, water struck levels were locally very deep at around 240 m below the ground surface although water rest levels were usually at less than

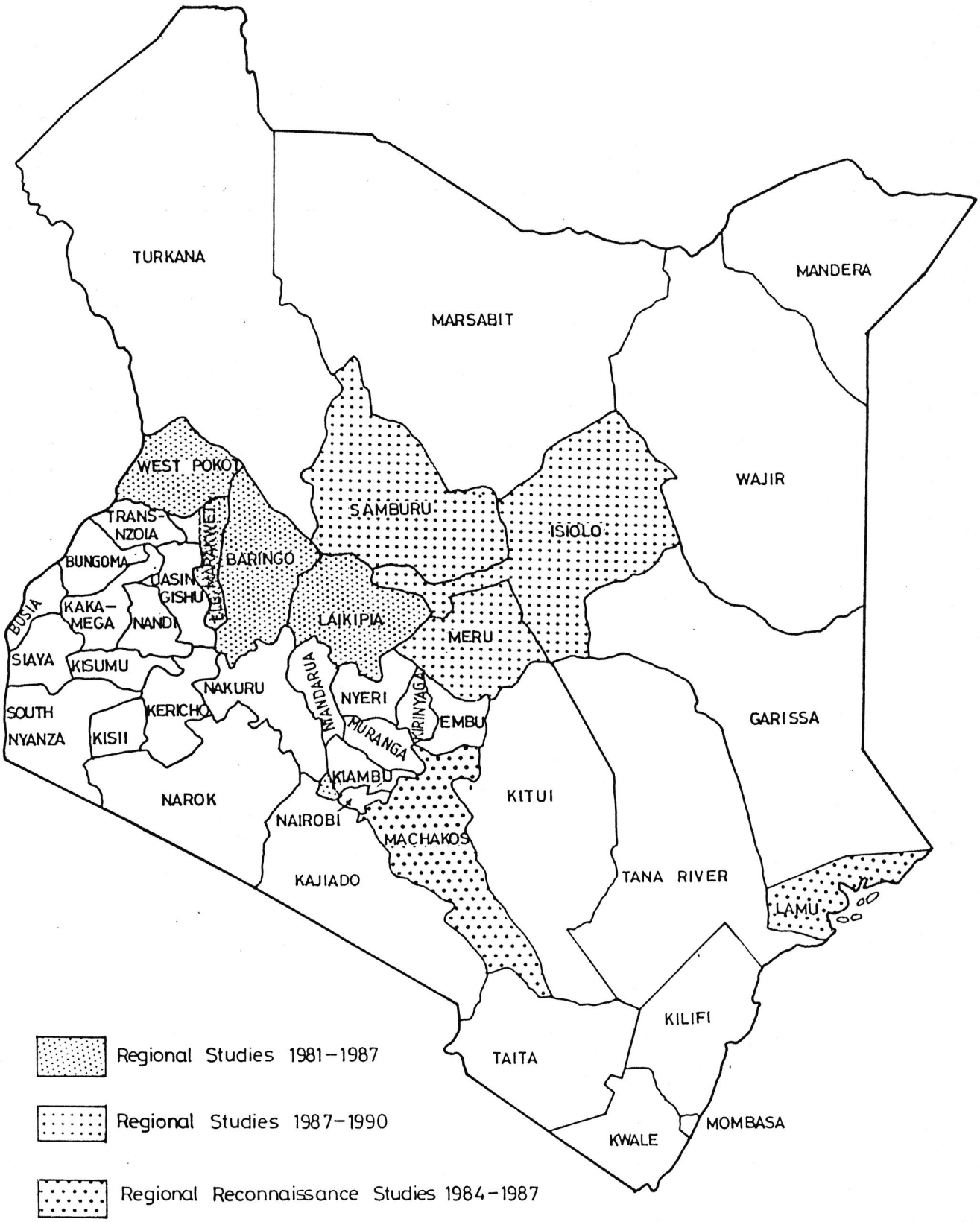


Fig. 1.1 Regional Assessment Studies under the WRAP Programme 1981-1990

1. INTRODUCTION

1.1 Scope of the Present Study

The Water Resources Assessment Study in Samburu District was carried out within the framework of Phase III of the Water Resources Assessment and Planning Project (WRAP). This Project is a joint venture between the Water Resources Division of the Ministry of Water Development, Kenya and TNO-Institute of Applied Geoscience, Delft, The Netherlands.

The activities of WRAP in Samburu District include:

- a Water Resources Assessment Study
- District Water Development Study

This report presents the results of the Water Resources Assessment Study. The Study was carried out from August 1987 until July 1990.

1.2. Description of the Study Area

1.2.1 Location

Samburu District is located in the Rift Valley Province and is bounded by five districts: Turkana to the west; Marsabit to the northeast; Isiolo to the east and south; Laikipia to the south-southwest and Baringo to the south-west (Figure 1.1). It covers an area of about 20,810 km^2.

Until recently the District was administratively divided into three Divisions (Baragoi, rroki and Wamba), 21 Locations and 69 Sub-locations. Since last year, Wamba division has been split up into two parts and two new divisions were created: Wamba and Waso. These administration changes, however came too late to be included in the report. Only Figure 1.2 could be updated. Everywhere else, in the report, a reference to Wamba Division should read as Wamba and Waso Division.

1.2.2 Physiography

The district is situated on the eastern flank of the main Kenyan Rift system. The Suguta valley and its escarpments forms the western boundary of the District. The highest elevated parts of the District include the Leroghi Plateau and the mountain ranges of Nyiru, Ndoto and Mathews (Figure 1.2). The altitude of these highlands ranges between 1,500 m and 2,500 m above sea level. The rest of the district is a continuous basin which slopes towards Lake Turkana and from Mathews Range eastward to Isiolo and Marsabit. The central plains around Baragoi and Barsaloi range from 1,000-1,350 m above sealevel. The lowest parts in the district on the western and eastern boundary have an altitude of about 750 m.

The perennial Ewaso Ngiro - which is Kenya's third largest river - forms the southern boundary of the district. Otherwise drainage is by seasonal or even episodic streams

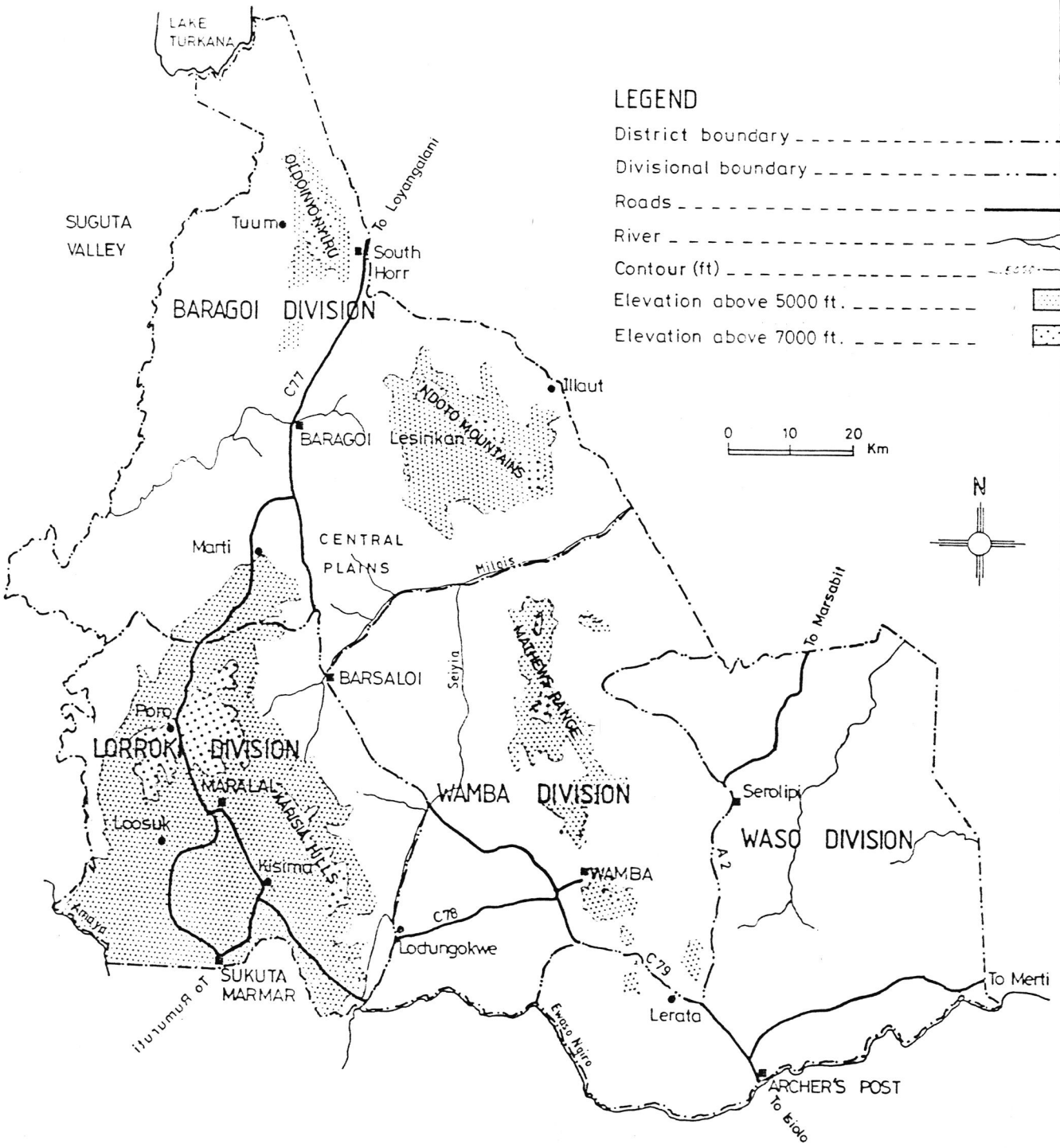


Fig. 1.2 Samburu District Location Map

(laggas), of which the main river system Seiya-Barsaloi-Milgis drains the Leroghi Plateau and the central plains of the district.

1.2.3 Climate

In general the highland areas and the southwestern plains receive the highest annual rainfall in the district, between 600 mm and 1,000 mm. The central basin bounded by the El-Barta and Swuari plains and the lowlands east of the Mathews Range are the driest with an annual precipitation of between 200 mm and 500 mm.

Temperatures in the area vary with altitude and are generally between 24°C mean minimum and 33°C mean maximum. The central part of the district and the area east of Mathews Range exhibit the highest temperatures.

1.2.4 Soils and Land Use

The best soils in the District are the deep, red soils of the Leroghi Plateau and the dark, deep, well drained, clay loam soils on the mountain ranges. Otherwise soils are poor with shallow, rocky and stony soils on the volcanic hills and central plains, which only support sparse vegetation. The latter soils have suffered much from erosion.

The land in Samburu District may be classified as either high, medium or low potential depending on the annual rainfall in the area (Table 1.1).

Table 1.1 Land Classification in Samburu District

Zone	Area (ha)	Land Use Patterns	Annual Rainfall (mm)
High Potential and Medium Potential	140,000	3.5% under wheat, maize and beans and the rest communally grazed. Presently communal grazing land. Adjudication into group and individual ranches in progress.	875 and above
Low Potential	1,612,000	This zone includes 64 km² for Samburu Game Reserve	612 - 875
Others	328,900	Includes 325,000 ha. of gazetted forests and other land set aside for special purposes.	612 or less
Total	2,080,900		

Source: District Development Plan 1989 - 1993

The high potential land is found mainly in Lorroki Division where rainfall is highest. The area of the medium potential zone is not fully documented yet but is known to include a small part of Lorroki Division to the east of the plateau and minute parts of Baragoi Division and Wamba Division. The low potential zone covers most of Baragoi and Wamba Division and the rest of Lorroki Division. This zone is either marginal or semi-desert. Other land includes gazetted forest land, Samburu Game Reserve and land set aside for military purposes.

The high altitude of the mountain ranges has resulted in indigenous forests which are all gazetted and preserved for rain catchment. Apart from occasional and controlled grazing during drought periods, no commercial exploitation is permitted.

Land adjudication started in 1972 and individual and group ranches have been created in about 40% of the District. The present tendency is to further subdivide the group ranches. Individual farmers are gradually taking up agriculture at Loosuk and Poro where maize, beans, potatoes, vegetables and other crops are doing well. Sorghum and millet have been grown on a very small scale around Baragoi and Wamba during the long rains.

1.2.5 Population

Table 1.2 illustrates the population growth in 1969 until 1979 and the projected growth for 1993 and 2013. The data for 1988 are also based on projection as data from the census in 1989 are not yet available. For the applied growth rates reference is made to the District Water Development Plan, Report 1, WRAP 1989.

Table 1.2 Population 1969-2013

Division	Area Km²	Census Data		Projections		
		~ 1969 Total	1979 Total	1988 Total %	1993 Total %	2013 Total %
Lorroki	4,010	29,385	34,753	44,400	50,000	93,000
Baragoi	7,022	19,982	18,764	24,000	25,500	37,000
Wamba	9,769	19,702	23,391	29,900	30,900	38,000
District	20,801	69,519	76,908	98,300	106,500	168,000

The population of Samburu District numbered 76,908 in 1979 and is currently estimated at 98,300, reflecting an estimated annual growth rate of 2.76%. Ethnically, 75% of the population belongs to the Samburu tribe, 17% to the Turkana tribe, the remaining 8% is made up of people from a large variety of Kenyan tribal groups.

Samburu is a relatively sparsely populated district. Within the district a large part of the population lives in the Lorokki Division, that has the highest population density in the district, but remains far below Kenya averages.

Table 1.3 Population Distribution

Administrative Division	Area		1988-Population Estimate				Rural Population Density/km²
	km²	%	Total	%	Urban	Rural	
Lorroki	4,010	19	44,428	45	22,662	21,766	5.4
Baragoi	7,022	34	29,880	31	4,887	24,993	3.6
Wamba	9,769	47	23,983	24	7,603	16,380	1.7
District	20,801	100	98,291	100	35,152	63,139	3.0

The majority of the population lives dispersed over the land in isolated non-permanent housing (manyattas), oriented for services toward 21 trading centres. It is only in those centres that one finds concentrations of population in village type settings.
Mostly, the rural people are pastoralists of the nomadic type. This means that although a particular household or clan belongs administratively to a particular sub-location, the

entire (or at least part of the) clan may be following its' livestock in search of fodder and water. Little is known about the movements of population and livestock, however it would seem from interviews during field visits that mostly it is only the young men (Imurani or Moran) that move with the bulk of the livestock. This group makes up for about 20% of the total rural population.

The population of the 21 trading centres totalled 20,718 persons in 1979, varying between a mere 37 (Lodokojek T.C) and 10,230 (Maralal)[1]. In 1979, 28% of the population was living in the trading centres. The 1988 estimates indicate 36% of the district population to live in the trading centres, indicating a strong tendency towards urbanization, and depopulation of the rural areas.

1.2.6 Livestock

Livestock is the major source of living and the prime social status indicator for the (rural) Samburu population. Livestock outnumbers the rural population by far. In 1988, the ratio between livestock and human was 2.3. Lorroki Division is suited for dairy and beef cattle while the drier Baragoi and Wamba Divisions generally support camels, goats, sheep and a limited number of cattle.

The livestock population has dramatically decreased between 1983 and 1985. This is primarily due to the 1983/84 drought when 50 to 75% of cattle died because of lack of fodder and water. Currently livestock numbers have recovered to pre-drought numbers because of the adequate rainfall in recent years.

Livestock potential has not been assessed in detail, but estimates range between 4 acres/L.U. for Lorroki Division, and 10 acres/L.U. for Baragoi and Wamba divisions (source:livestock production office Maralal), from which a district livestock potential of about 350,000 L.U. can be derived. However, other sources (Farm Management Handbook, 1983) quote a remarkably lower potential, concluding that present livestock numbers are already in excess of sustainable numbers. The rangelands survey in 1989 is expected to provide revised potential livestock densities.

The mobility of cattle, and with it a part of the population (herders) is substantial. The movements have not been analyzed systematically, but seasonal treks over distances in excess of 100 km are quite normal. These treks are triggered by perceived needs for quantity and quality of fodder and water, and by attempts to prevent and reduce disease.

[1] WRAP estimates the urban population of Maralal lower at 8,000, by assuming that the 1979 census figure of 10,230 actually includes a rural population, which lives in the rural parts of Maralal location.

2 GEOLOGY

2.1 Previous Studies

The first studies on the geology of Samburu District were conducted by Rosiwall (1891), Von Hohnel (1894), Cavendish (1898) and Champion (1935), which are referred to in Shackleton (1946) and Key (1987).

Systematic mapping of the district began in the fourties. Shackleton (1946) mapped the south-western part of the district. Nearly 20 years later, in 1963, Dodson, Rix and Baker published studies of the South Horr, Kauro-Merille and Baragoi areas respectively. In 1967, Jennings published a study on the geology of the Archer's Post area.

These reports cover the whole district except for the Ndoto area and a small part of Samburu situated west of 36° 30'. This area was mapped between 1965 and 1970 by the East African Geological Research Unit (EAGRU) and presented on two geological maps: EAGRU, 1976 and 1978.

More recently, in the beginning of the eighties, a joint Kenyan-British team began a new survey of the area between 0° and 4° North and 36° and 38° West. Samburu District lies wholly in this rectangle.

The boundaries of the respective study areas are indicated in Figure 2.1.

The geology of the District was simplified and presented on the geological map (Plate 2.1) which was prepared on the basis of the afore mentioned studies.

The whole district is covered by aerial photographs and Landsat images.

2.2 Geological Setting and History

The district which lies on the eastern shoulder of the Rift Valley, can be subdivided into two major geological divisions:

1. The eastern side covered mainly by the crystalline Basement System which occupies roughly two thirds of the district. The System also plays host to some occasional volcanic outliers which seemingly originate from local vents.

2. The western side covered by Tertiary Volcanics of the Rift Valley.

The crystalline Basement System belongs to the Precambrian era and as such constitutes the oldest rocks in the district. It forms part of the Mozambiquan Orogenic Belt and was first deposited as sediments which were later altered by tectonothermal events to form the present Basement System. Successive stages of uplift and erosion followed, lasting until the beginning of the Tertiary when lavas flooded to the Basement System, producing basalts in the early stages and phonolites and trachytes in later stages. Recent deposits which consist of alluvium and colluvium, calcareous and lacustrine sediments, agglomeritic ash and residual soils have resulted from weathering of the Basement and the Tertiary volcanics with subsequent deposition on the lower regions and river valleys.

Fig. 2.1 Geological Mapping Diagram

2.3 Stratigraphy

The following stratigraphical description summarizes the geological studies listed in section 2.1. According to these studies, the rock formations can be divided into four major groups.

a) Metamorphic rocks forming the Basement System
b) Igneous intrusives
c) Tertiary volcanics
d) Quaternary volcanic and sediments

The areal distribution of the main rock formations is shown on Plate 2.1. A summary of the lithostratigraphy is given in Table 2.1. A short description of the main rock units is given below.

2.3.1 Basement System

These are the oldest rocks in this region and are part of the Pre-cambrian Mozambiquan Orogenic Belt. They comprise various types of sediments and volcanics which were transformed by regional metamorphism into gneisses, schists, quarzites and marbles. In addition, large areas are underlain by migmatites.

These metamorphics underlay the eastern 2/3 of the area while within the volcanic western 1/3 of the area one major and a number of minor outcrops can be found.

The most important rock type of the Basement system in Samburu is that of the hornblendebiotite and leucocratic-biotite type but many other types do occur.

2.3.2 Intrusives

These rocks are mainly granodiorites and granites but also include relatively small outcrops of pegmatites, quartz reefs, aplites and diorites. Only the major outcrops are shown on the map: foliated granites which often form major inselbergs and hills, and granodiorites outcropping east of the Mathews Range.

2.3.3 Tertiary and Quaternary Volcanics

These deposits overlie the metamorphic rocks of the Basement system. Locally, underneath the volcanics, subvolcanic deposits of probably Lower Miocene age are found. These deposits are the erosion products of the Basement system rocks. They usually consists of well rounded pebbles.

The volcanic rocks in Samburu District are products of eruptions which started in the Lower Miocene.

In the west, on the Rift Valley Shoulder, the lower layers are more basaltic and the upper ones more phonolitic and trachytic. In this area, volcanicity began with the extrusion of an extensive series of basaltic pyroclasts and lavas, the Samburu basalts. Outcrops of this formation are widespread.

Table 2.1 Simplified Lithostratigraphic Table of Samburu District

PERIOD	EPOCH	FORMATION	LITHOLOGY	maximum THICKNESS (metres)
QUATERNARY	PLEISTOCENE/RECENT	Superficial deposits	Alluvium, calcrete, sand-rich colluvium, gravels, dune, pumice , agglomerates	
		Emuruangogolak trachytes	Trachytic lavas and tuffs with minor basalt flows	200
TERTIARY	PLIOCENE	Emurua Giring trachytes,	Trachytic lavas and tuffs	500
		Tirr Tirr basalts + trachytes	Trachytic lavas and tuffs and minor basalt flows	300
		Kauro, Merille, Marti Serteta basalts	Olivine basalts	6
	UPPER MIOCENE	Losiolo phonolites	Phonolitic lavas and tuffs	600
	MIDDLE MIOCENE	Kamolingalan basalts	Basaltic lavas, tuffs and related sediments	1000
		Lopet phonolites	Phonolitic and trachyphonolitic lavas and tuffs	800
		Towana formation	Phonolitic tuffs	200
		Alengerr tuffs	Trachytic and phonolitic tuffs, minor sediments and basalts	270
		Katomuk tuffs	Phonolitic tuffs and lavas	300
	LOWER MIOCENE	Samburu Basalts	Basaltic pyroclasts and lavas	
		Intrusives	Trachytes, phonolites, foyaite, basalts, dolerites, gabbros, quartz reefs, granites, pegmatites,aplites,shonkinites,monzonites, syenites, granodiorites, serpentinites.	
PRE-CAMBRIAN		Basement System	Pelitic to semi-pelitic gneisses,granitoid gneisses, pegmatites,schists,	

During the Middle and upper Miocene, a phase of a plateau phonolite eruptions followed (fissure volcanism). The Lopet Phonolites, Towana formation, Losiolo phonolites and Katamuk tuffs are important members of this phase. Their total thickness is about 1000 m.

Finally, up to 1000 m of Late Miocene to Recent basalts and trachytes were erupted over the western and northern extremities of the eastern shoulder. The Tirr basalts and trachytes, and Emuruangogolak belong to this phase. The Teleki's Volcano at the northern edge of Samburu District erupted at the beginning of this century.

In the eastern part of the District, volcanicity began in the middle Miocene with the deposition of plateau phonolites (Sumatia) and basalts (Middle Miocene to Pliocene: Nkanos, Serteta, Ampara, Errerr, Ilaut).

2.3.4 Quaternary Sediments

The Quaternary Sediments include alluvial infill and overspill to most water courses, calcareous deposits, cancar limestone, lacustrine deposits, agglomeritic ash, residual soil and colluvium passing laterally into talus at the bases of major hills. Sinuous and braided shallow channels related to sporadic flow after the last heavy rains are marked by medium grained sands with gravel bars which top the alluvium.

Residual soils are rarely more than 2 metres thick and are mostly red-brown sandy loams with local variations related to underlying bed-rock. All colluvium is a crudely stratified poorly sorted mixture of lithic clasts, sand silt and clay which is thickest around peripheries of major hills. Calcareous deposits are found to occupy river valleys.

2.4 Structures

The most important structures in the district are the faults and fractures, which occur both in the Basement System and in the Volcanics.

The general trend of the major lineaments in both Volcanics and the Basement System is roughly north-south. They are easily observed on both the aerial photographs and Landsat imageries at higher altitudes, but less easily in the lower regions where they tend to be obscured by red sandy soils.

The main lineaments are occasionally cut across by younger ones, especially in areas underlain by granitoid gneisses.

Lineaments within the volcanics are more easily discerned in the basaltic rocks, while the ones in the phonolites are covered by red and loamy soils formed from the weathered rocks.

One conclusion which can be drawn from the aerial photographs is that the river channels in the Basement System are fracture controlled as is manifest in the sudden angular changes in the channel courses.

2.5 Economic Geology

Minerals found in the district are of very little economic importance as the deposits are small. Most of them occur within the pegmatites in the Basement System. They include, asbestos, chromite, mica, magnetite, copper, talc and corundum. Significant finding of diatomite, gemstones (beryl, sapphire, green garnet) and radioactive minerals warrant detailed follow up.

There is significant mining of vermiculite at Doinyo Uasin for export.

3. GEOPHYSICS

3.1 General

This chapter contains a summary of the geophysical investigations carried out by the Water Resources Assessment and Planning Project in Samburu District. The investigations were done in all the three divisions, i.e. Wamba, Baragoi and Lorroki consecutively.

The aim of the geophysical surveys by WRAP in Samburu District was to find suitable sites for boreholes for water supply in priority areas indicated by the local administration and also to compile a report on the findings with regard to groundwater availability in the District. To this end principally the electromagnetic profiling method (EM) was applied. It proved to be very fast and successful. Some supplementary vertical electrical soundings (VES) as well as Apex Max-Min electromagnetic profiling (AP) and resistivity profiling (RP) were also carried out. The details of every site investigated, final interpretation of the collected data and the results of the drilling programme are given in Appendix 3.1 to 3.5.

3.2 Previous Geophysical Studies

A limited number of VES and resistivity profiles (RP) were carried out in Samburu District by the Ministry of Water Development and Groundwater Survey Kenya Limited for locating borehole sites. Their contribution to the success of the present investigations however is negligible.

3.3 Geophysical Fieldwork

3.3.1 Selection of Locations and Method

The geophysical fieldwork was concentrated in a limited number of locations.

According to the priorities, the project selected 13 locations in Wamba, 11 in Baragoi and 5 in Lorroki Division for geophysical site investigations. To establish the presence of any geological structures, a preliminary aerial photo-interpretation and ground checks preceded the geophysical work at all the priority areas. On account of these, several sites were identified and investigated within the priority areas to select drilling sites. The geophysical investigations were concentrated in areas noted to show lineaments as inferred from aerial photos, landsat images, geological maps and also from reconnaissance survey. In Basement areas, these lineaments were investigated principally by electromagnetic profiling (EM) to establish their existence, exact location and other relevant features. Generally, also some vertical electrical soundings (VES) were executed to determine the thickness of the unconsolidated overburden (weathered zone and/or alluvial deposits).

In volcanic areas, mainly VES were carried out to establish the total thickness of the volcanic cover.

At the beginning, a comprehensive test was set up in Wamba Town in order to find out the most effective way of borehole siting in Samburu District especially in the basement rock areas. The methods involved were:

- vertical electrical soundings (VES)
- Resistivity Profiling (RP)
- Apex max-min electromagnetic profiling (AP)
- EM-34 electromagnetic profiling (EM)

This comparative test concluded that although RP provides very reliable and consistent field data, the execution is quite time consuming and hence slow.

The Apex max-min Equipment is fast in performance. However due to the large number of alternative combinations of frequencies and coil separations each combination giving a different response for a particular buried structure, it requires a lot of effort to discover which combination will produce the sharpest anomaly for the structure.

Hence electromagnetic profiling with the EM-34 equipment was adopted, this being about 3 to 5 times faster, and maintaining almost the same resolution within its given depth penetration range.

3.3.2 Resistivity Profiling

Resistivity profiling was only conducted in Ledero and Wamba Town where the already mentioned comparative test was conducted. 5 profiles with a total length of 5,780 m were run in Wamba and 3 profiles with a total length of 265 m were carried out in Ledero. The selected current electrode distances in the profiling (AB/2) were 25m, 50m and 100m. Profiling was done with a constant station interval of 25m. In Ledero, three resistivity profiles were conducted.

3.3.3 Electro Magnetic Profiling

The two methods of electromagnetic profiling applied were Apex max-min (AP) and EM-34 (EM). Only 2 AP's were carried out in Wamba Town. The method, though good in performance, is rather laborious in execution. The total length of the APs is 1,250m.

The EM-34 profiling method was thus adopted widely for all the electromagnetic profiles run. In Wamba Division a total of 75 EM profiles were done covering a total distance of about 78,500m. In Baragoi Division, 30 EM profiles were executed covering a total distance of about 23,850m, while in Lorroki Division, 42 EM profiles were run covering a total distance of about 24,540m. In the Apex max-min electromagnetic profiling, all the five different operating frequencies were used, with coil separations of 25 m. In the Apex max-min, the horizontal loop mode was applied, this being the standard mode of operation, whereas in the EM-34, the vertical loop mode was selected for application because of its lesser sensitivity to external disturbances, compared to that of the horizontal loop mode.

3.3.4 Vertical Electrical Soundings

A total of 63 vertical electrical soundings were executed in 13 areas of Samburu District. These soundings were carried out in sites which were either observed to be promising from the reconnaissance survey or anomalies were noted from the electromagnetic profiles. The Schlumberger configuration was used in executing the soundings. Field data was recorded on the relevant graphic sheets and preliminary interpretation of the curves done on site of investigation as a measure to determine the most appropriate EM depth penetration range (i.e. coil separation), and as a control of possible measuring errors.

3.4 Data Processing and Interpretation

The acquired geophysical field data were stored in a computerized data base system, designed for the storing and processing of all relevant data within the present assessment study.

A quantitative interpretation of the VES from both metamorphic and volcanic terrains was done using the indirect method, based on the TNO, VES, version 4.20-S, program.

The interpreted data, i.c. layer thicknesses and layer resistivities, were correlated to geological or geohydrological layer units.

Where necessary, re-interpretation was carried out after the completion of the exploratory boreholes.

Concerning the RP, AP and EM profiles, a quantitative analysis was done correlating characteristic anomalies with geological features, e.g faults, fault zones, graben like structures, alluvial fill. The identification of such structures were of decisive importance for the correct localization of the borehole sites.

3.5 Summary and Conclusion

The conclusions drawn from the various geophysical findings in the investigations carried out indicate the effectiveness of the geophysical methods applied. The results of these investigations have been used to locate the various boreholes that have been drilled by the project in Samburu District. The general finding from the geophysical survey are that:

1. In the Basement areas, geophysics is an effective means in locating tectonic structures (faulted and fractured zones) and the thickness of the weathered layer.

2. In the old river channels and valley zones, geophysical methods are useful in establishing the lateral extent and thickness of the alluvial layer and the water quality.

3. In the volcanic areas, the total thickness of the volcanic cover can be established or approximated.

A total of 16 boreholes were drilled in Samburu District, out of which two were dry and 12 productive. Two boreholes, which were located in an extremely thick colluvial deposit, could not be completed because of serious caving.

It should be noted, that the two dry boreholes were drilled in the very early stage of the drilling program, which indicates a high success rate after gaining some experience.

As a conclusion, the geophysical survey, together with the exploratory boreholes and test pumping played a prominent role in the data acquisition for the assessment study.

In basement areas, especially the EM-34 technique is useful by its simplicity, speed and high resolution to detect fault zones suitable for water accumulation.

However, in relatively narrow structures, no reliable prediction can be given about the water quality or the expected quantity. On the other hand, in saturated alluvial or colluvial deposits a distinction can be made between fresh and saline water occurrence by means of vertical electrical soundings.

In volcanic areas, there is a fairly high statistical probability of ground water occurrence, mainly in weathered or fractured volcanic rocks, coarse pyroclastic layers or old land surfaces. In the actual situation, the contribution of the geophysical methods to adequate siting is relatively small, if not negligible. For an improvement of the success rate, a much more extensive detailed VES survey would be required, whether or not combined with a seismic survey, which was beyond the scope of this study.

In the present study, only a limited number of VES was carried out in order to get a general idea about the thickness of the volcanic cover, and hence the vertical extension of the potential aquifer.

A detailed description of the results is given in Appendix 3.5.

4. HYDROLOGY

4.1 General

The hydrological component attempts to give some information on the spatial and temporal distribution of the surface water resources. This has been done by considering the rainfall, evaporation and runoff distribution in the district. This gives some indications to the possibilities and limitations that exist for the utilization of the surface water resources in the district.

The hydrological study area covers the area formed by the Samburu District boundary except for a very small part of the Amaya river catchment which includes tiny portions of Laikipia and Baringo Districts (see Plate 4.1).

The Ewaso Ngiro river is the major perennial river system and forms the southern boundary of Samburu District. It has been studied to some detail upto the area upstream of river gauging station (RGS) number 5E3 at Archer's Post. The information is contained in the Water Resources Assessment Study Report, Laikipia District (Ministry of Water Development, 1987).

The District lies in a semi-arid to arid environment and therefore has limited permanent surface water resources in form of perennial rivers. Except for the Ewaso Ngiro, else where in the district are only a few perennial streams and springs. The rest of the river water courses are laggas and are the most numerous in the district. The perennial ones include the Amaya, South Horr and Tuum streams and some springs in the Mathews range near Wamba, and at Kichich. For some of these preliminary estimates were made concerning their reliability as water sources by using the scanty data available mainly collected by the project since late 1987.

Some dams exist on seasonal rivers especially in the area near Maralal. The project has since late 1987 collected data on the Nundoto reservoir. This included data on rainfall, evaporation and daily water levels.

Rainfall and pan evaporation data have been evaluated to give some information of their quantity and distribution in the district. This was based on both the existing data and that collected by the project.

4.2 Previous Hydrological Studies

A summary of previous studies in the district relevant to the surface water resources availability is presented below.

Northern Frontier Province Water Conservation Scheme, the Dixey Scheme Report, 1950-55

The purpose was to find ways by which water could be temporarily provided in areas far from permanent water supplies.

The report observed that although the Dixey scheme of 1943 had recommended boreholes, the high cost of successful drilling and experience at the time showed that reliance on surface water supplies from storage facilities such as small dams, pans etc would be more economical in Samburu district.

Howard Humphrey's and sons (1958) - Northern Frontier Province and Samburu District Water Development Scheme, (1950-58) Report to Kenya Government

It was observed that the laggas carry tremendous volume of water during the heavy rains but after the floods have passed, water was only available at shallow depths in lagga beds at some places.

The report also noted that to the west of the Mathew's range, the main laggas could be relied on to supply water from the sands at a few feet below the surface for four to six months after the rains. The report recommended construction of water conservation structures in the district but discouraged large dams on the basis of topographical and hydrological considerations.

Ministry of Water Development, Maralal Water Supply Preliminary Design Report by Howard Humpbreys and Sons (EA) - Consulting Engineers -1976

The report made proposals and recommendations for possible sources of water supply to the Maralal township. On the surface water situation, it was noted that no perennial rivers existed within the Maralal area. Only seasonal streams that carry water during the rains existed.

The Nundoto catchment above the old Lemisigiyo dam was estimated to have an annual runoff yield of 372,000 cubic meters. The new dam that supplies water to the township is in the Nundoto catchment upstream of the old one. Its construction had been recommended by this report.

Ministry of Water Development, Wamba Water Supply Preliminary Design Report by Wanjohi Consulting Engineers 1981

The report made proposals and recommendations for possible sources of water supply to the Wamba area. On the use of surface water resources around Wamba, the report recommended impounding of the Wamba river in the Mathews range some 1.5 km upstream of the Game Department camp. It was noted that although the Ewaso Ngiro river had adequate water to meet the demand, the distance of 35 km to Wamba and the difficult terrain made costs prohibitive and therefore it was not recommended.

Farm Management Handbook of Kenya Volume II, Natural Conditions and Farm Management Information Part - B, Central Kenya - (Rift Valley and Central Provinces) Ministry of Agriculture

The report assessed the Agricultural potential of Samburu District. Information on the annual and seasonal rainfall distribution was summarised in tables and illustrated with maps.

Ministry of Water Development, Water Resources Assessment Study in Laikipia District, May 1987

The Ewaso Ngiro basin was studied in some detail. The river forms the southern boundary of Samburu District.

Hydrological data on the runoff characteristics of Ewaso Ngiro at Archers Post for the runoff station number 5E3 is contained in this report. This information is useful to Samburu District for any possible future use of the river as a water source.

4.3 Hydrometeorological Network

4.3.1 Rainfall Stations Network

The present rainfall stations network covers the district inadequately. There are some 39 rainfall stations in Samburu district but they cover only less than one half of the district because they are concentrated in a few areas. A large portion of the district is unrepresented by rainfall station coverage (see Plate 4.1).

Most of the rainfall stations in the district belong to the Kenya Meteorological Department. In the Wamba area the Arid and semi-arid lands (ASAL) project has installed some raingauges. Some others were installed or rehabilitated by the WRAP as summarised in the WRAP progress report, October 1988.

The main problems affecting rainfall data collection at established rain gauge stations are vandalism and negligence by some observers. Our regular monthly inspections improved on data recording but vandalism still remained a problem at some places such as Lonkewan and Morijo.

Expansion of the rainfall network to be representative of the whole district could not be done by the project due to nomadism, vandalism, and remoteness. Nomadism makes continuity of records a problem and therefore only areas with permanent settlements can maintain useful rainfall records. Vandalism is prevalent and therefore only relatively secure places such as DO's. Chiefs, Mission Centres are reliable. Such centres are unevenly distributed over the district and therefore representative coverage was restricted. Remoteness made network expansion difficult because it would hamper adequate inspection in many areas.

4.3.2 Evaporation Stations Network

The surface water Section of the Ministry of Water Development uses class A Evaporation pans for the estimates of potential evaporation from open water surfaces.

When the project moved to Samburu District, there was only one such a pan in operation at Archer's Post in the southeastern part of the District.

The project installed four new Class A pan evaporation stations at South Horr in the North, Wamba in the east, Amaya in the southwest, and at Nundoto dam near Maralal township. The Central part including the Barsaloi - Baragoi area was excluded as the pans require regular daily supply of water which could not be guaranteed in these

parts of the district (see Appendix 4.2 for the list of the stations).

In early 1988, the old evaporation pan at Archers Post was replaced with a new one as it had started leaking. Regular monthly inspections of the evaporation pan stations was done by the project for data collection, inspection, and maintenance.

4.3.3 Runoff Stations Network

The Ewaso Ngiro river which forms the southern boundary of Samburu District is the only significant perennial river system of the district. Most of the water courses in the district are ephemeral, only carrying water during and shortly after heavy rains. Maintaining regular gauging stations on such water courses is in most cases impracticable.

An old gauging station number 5E3 exists on the Ewaso Ngiro at Archer's Post. Within the district, there was no operational regular gauging station. A few small streams and springs exist within the district which are perennial. The most significant of these are the Amaya and South Horr streams on which the project installed regular gauging stations. Daily water levels have been recorded since late 1987 and regular monthly discharge measurements were taken by the project.

On two other springs at Tum and Kichich, miscellaneous discharge measurements were taken during the field visits to those areas. Regular gauging stations were not established as they lacked suitable sites.

The new Nundoto dam near Maralal township is the major source of water for the town. It is located on the ephemeral Nundoto river. On this dam, three staff gauges covering 0-4.5 m range were installed to measure daily water levels.

The Wamba river which originates from the Mathews range is said to be perennial in the upper reaches. The stretch where it is said to be perennial is in a rugged terrain high up in the ranges. This makes access very difficult. A regular gauging station could not therefore be established on this river. Due to the difficult access, obtaining records on water levels and discharge measurements would be a big problem.

For the locations of the gauging stations, see Plate 4.1.

4.4 Rainfall

4.4.1 Available Data

Rainfall data in Samburu District is limited in areal coverage, length of record, and continuity of observations. The earliest rainfall observations were made at Maralal D.C.'s office rainfall station number 88.36.00 from 1935 onwards. Other stations with relatively longer records are at Baragoi D.O's office, Wamba D.O's office and Archer's Post (see Appendix 4.1).

In the majority of the other rainfall stations, observations started in the early seventies. Most of them have widespread discontinuity in observations. Out of the 39 rainfall stations that have been operated in the district and for which records are available,

only thirteen have more than ten years record. Of the thirteen, only four have more than thirty years of complete record.

The source of all the available data upto 1986 was the Kenya Meteorological Department (KMD). The surface water Section of the Ministry of Water Development copies from KMD and stores the records. These are on monthly basis. The updating for the 1987 and 1988 rainfall data was done directly in the field during the routine hydrological safaris.

All the available data from the 39 stations within and nearby the District were computerized in a PC (Personal Computer) for storage and analysis. Fourteen rainfall stations with complete rainfall records for ten years and above were selected and analysed for use in the rainfall section of this report. Two of these at Tangulbei and Sosian are outside the district but were included as they are close to the district.

Generally the southwestern plains and the Leroghi plateau receive an annual rainfall of between 500-700 mm. The central basin area bounded by the Elbarta and Swari plains constituting the upper Milgis river and the plains east of the Mathews range are the driest in the district with annual average rainfall of between 200-500 mm. The almost continuous mountain belt in the north and east which includes the Nyiro, Ndoto, and Mathews range receives the highest rainfall in Samburu generally of the order 750 - 1250 mm p.a.

4.4.2 Monthly Rainfall Distribution

Some statistical characteristics of the monthly rainfall data are summarized in Appendix 4.4 Graphical presentation of the average monthly rainfall distribution is in Appendix 4.4.

The statistics show that the monthly rainfall is strongly variable both spatially and temporally. The high coefficients of variation indicate that the amount of monthly rainfall to be expected is highly variable from year to year.

The periods with low and high rainfall occur at different times in various parts of the district. Table 4.1 summarizes the occurrence of the rainfall patterns.

Table 4.1 Low and High Monthly Rainfall Distribution

REGION	AREAS INCLUDED	LOW RAINFALL	HIGH RAINFALL
Northern Part	South Horr, Baragoi	June - September September	April, November April, November
Eastern	Serolevi	June - October	April, November
South-East	Archers Post Samburu Game Wamba	June - September June - September June - September	November, April April, November April, November
South-West	Maralal, Poro Suguta Marmar	December - Feb. January - March	April-May; July-August July
South	Lodungokwe	April - September January - Feb.	November, April

In most areas, in the district, the wettest months are April and November, while the driest periods are around June to September and January to February. The area to the southwest of the district (Maralal, Poror, Suguta Marmar) has a distinctly different monthly rainfall distribution. This is due to the effect of the continental rains. The wettest month in these areas is July while January is the driest.

4.4.3 Seasonal Rainfall Distribution

In most parts of Samburu district, rainfall occurs in two distinct seasons with two weak peaks in April and November. The two seasons (long and short rains) contribute over 70% of the total annual rainfall except for those areas where continental rains are significant (see Table 4.2).

The continental (middle) rains occur between June to August. These are significant in the southwest of Samburu District where they contribute to about 40% of the total annual rainfall (see Table 4.2).

The areas around Poror, Maralal and Suguta Marmar receive the highest proportion of rainfall during the continental rains. The eastern and southeastern areas around the Wamba and Archer's Post area receive both the long and short rains in approximately equal proportions. In the northern parts of the district, the long rains contribute more than the short rains (see Table 4.2).

Table 4.2 Average Seasonal Rainfall Distribution Expressed as Percentage of Annual Average Rainfall

STATION NAME	REG. NO.	ANNUAL AVG. (MM)	LONG RAINS (MAR-MAY)	CONTI-NENTAL RAINS (JUN-	SHORT RAINS (OCT -DEC)	SUM OF SHORT & LONG RAINS
Poro Forest	88 36 03	551	27	41	19	46
Tangulbei	89 36 19	703	35	36	14	50
Sosian	89 36 60	435	48	26	23	70
Sukuta Marmar	89 36 74	627	24	40	23	47
Wamba D.O	89 37 18	714	45	3	44	89
Wamba Game	89 37 69	779	50	4	37	87
Archer's Post	89 37 35	864	45	3	45	90
Samburu Lodge	89 37 63	396	42	2	44	86
Lodungukwe	89 37 93	504	34	13	42	76
Nundoto dam	WD. 656	570	24	30	20	44
Baragoi D.O	88 36 01	532	42	13	31	73
Maralal D.O	88 36 00	605	30	40	19	49
South Horr Mission	87 36 00	443	46	4	35	81

4.4.4 Annual Rainfall

Annual Rainfall Distribution

The annual rainfall distribution in the district varies both in time and space. The lowest is observed in the eastern part of the district. The highest rainfall occurs at elevated areas such as the Mathews ranges and Poror in the highland forested area.

Although generally the annual rainfall is directly correlated with altitude, the amount of total annual rainfall received is influenced by the local conditions. Thus Wamba at an altitude of 1,360 m receives more rainfall (average 714 mm p.a, 1937-88) than Maralal (average 605 mm p.a, 1936-88) at an altitude of 1950m. This difference is related to the rainfall distribution during the various seasons.

A rainfall map showing the median, instead of the mean rainfall, is shown as Plate 4.2. This map is based on available rainfall records. As a rule of thumb, the average is about 10% higher than the median. For an explanation why the median was used instead of the mean, and many other details on rainfall and its resulting growing season, reference is made to Jaetzold's report (1990) while a summary is given in Appendix 4.7.

The Mathews Range receives median annual rainfall of up to more than 1000 mm, while other mountain ranges such as the Karisia Hills, the Ndoto Mountains and the Ol Donyo Nyiru get up to 800-900 mm. Infact, these areas could receive even about 100 mm/year more from fog, dew and drizzle.

In sharp contrast, median annual rainfalls in the plains amount to only an estimated 300 mm in the plains west of Mathews Range and go down to a low of 200 mm in the eastern part of the District, near the Marti Serteta, east of Merille.

As illustrated by the graphs in Appendix 4.7, all over the district, there are more years with annual rainfall below than above the annual average. This indicates that dry conditions dominate most of the years.

The highest annual rainfall variability is to be expected at areas around South Horr, Archer's Post upto the Samburu Lodge area. At Maralal and Baragoi areas, it is relatively less variable (see Appendix 4.7).

Annual Rainfall Variation

The 5-year moving mean graphs were prepared to analyse the annual rainfall variation on the occurrence of periods of wet and dry years. The analysis was done for only four stations in the district with annual rainfall records longer than thirty years (see Appendix 4.1).

The years when annual rainfall is below the annual average for the area are considered as dry years whereas those above average are wet years. No trends exist. Sequences of dry and wet years exist.

At Maralal, little variations exist and there are no pronounced dry or wet periods except that the eighties appear to have been exceptionally dry for the area. The Wamba area shows large fluctuations in the peaks. The Archer's Post also shows some less pronounced fluctuations though slightly higher than Maralal.

The general conclusion is that the forties and the fifties were drier than normal. The sixties were wetter than normal whereas the seventies and eighties have been drier than normal.

Annual Rainfall Reliability

The frequency of occurrence of annual rainfall is useful for the long term planning in the water resources development and management.

Annual rainfall reliability analysis was done only for the areas where rainfall records of thirty years or more existed. For each rainfall station, the total annual rainfall for all the years of record were sorted in a descending order and then ranked.

The plotting positions were computed using the Weibul plotting position formula:

$$P = \frac{m}{n+1} x\ 100$$

Where: P = Percent probability of exceedance
m = Rank in ordered series
n = total years used

Graphs were computer generated (see Appendix 4.9).

The results indicate the proportion of time (years) in which on the average a certain amount of rainfall may be equalled or exceeded. Some examples are shown in Table 4.3.

Table 4.3 Annual Rainfall Reliability (mm)

STATION NAME K.M.D. NO.	RECORD PERIOD	ANNUAL AVERAGE	50%	60%	66%	70%	80%	90%
Wamba D.O 89.37.18	50	714	629	583	553	529	463	379
Maralal D.C 88.36.00	53	605	591	550	544	518	480	431
Baragoi D.O 88.36.01	50	532	514	489	474	463	426	381
Archer's Post 89.37.35	43	350	317	274	246	228	196	171

NOTE: The Annual rainfall values given under percentages are probabilities of exceedance. Probability of exceedance is the proportion of time that on average the annual rainfall will be equal to or greater than the stated value. For example, in 60% of the time (on average 6 out of 10 years), the annual rainfall around Maralal is likely to be equal to or greater than 550 mm.

Annual Maximum Daily Rainfall Frequency

The analysis for the maximum daily rainfall frequencies is important as it is of direct application in the design of various water related projects of economic importance.

The data may be used in the design of drainage networks, design floods for storage dams etc. These and some other water project designs are usually on the basis of a certain depth of rainfall to be expected during a selected period of time.

The analysis for the annual maximum daily rainfall frequency was done for four stations with longer than thirty years of record. The annual series of maximum daily rainfall were sorted and ranked in descending order. The plotting positions were determined by the Weibul plotting position formula.

The results were plotted on the Gumbel extreme probability paper. The Gumbel theoretical distribution was fitted to the data for the extrapolation of higher return periods of up to 100 years since the range of the data used was only up to 46 years. Some examples of annual maximum daily rainfall of some commonly used return periods in design works is presented in Table 4.4. The highest maximum daily rainfall amount is to be expected at Wamba (see Appendix 4.10 for graphs).

4.5 Evaporation

4.5.1 General

The problem of evaporation is very important in an arid and semi-arid region such as in Samburu District. In these areas, existence depends on very limited water supply.

Table 4.4 Annual Maximum Daily Rainfall Frequency

Rainfall Station	Reg. No.	Return Period in Years, Amount in mm			
		Tr: 10	25	50	100
Archer's Post n = 39	89.37.35	81.0	98.0	111.0	124.0
Baragoi DO n = 46	88.36.01	85.0	102.0	114.5	126.5
Maralal DC n = 46	88.36.00	63.0	73.0	80.5	88.0
Wamba DO n = 42	89.37.18	146.0	180.0	205.0	230.0

n = Number of years used
Tr = Return period

Note: Return period refers to the average interval in years for an event of a given magnitude to be equalled or exceeded. Thus, for example at Maralal once in fifty years, a maximum daily rainfall of 80.5 mm can be expected on the average.

Evaporation is a continuous reduction of available water from any body of stored water. It constitutes a major water loss from impounding reservoirs in arid and semi-arid regions. In the design of these structures, evaporation must therefore be estimated to determine the net volume of water available.

4.5.2 Monthly Evaporation

Data on monthly distribution of evaporation in Samburu for a relatively long period exists for only two places in the district. These are Maralal area and the Archer's Post area.

The Maralal data is extracted from the report by Woodhead on the "estimation of potential evaporation in Kenya". The Archer's Post data is based on evaporation pan observations (1946-88) (see Table 4.5).

The data for 1988 from the four project installed evaporation pan stations was analysed and the observed monthly distribution of evaporation for that year is summarized in Table 4.5.

On the basis of the data on potential evaporation estimate, the highest potential evaporation around Maralal is generally to be expected in March and the lowest in July.

The monthly potential evaporation expressed as a percentage of the annual total ranges from 7.3% in July to 9.7% in March. Generally the monthly evaporation appears to be fairly uniform around the Maralal area except for the months of June to

August and in November which may experience lower evaporation losses associated with cloud cover.

The monthly average pan evaporation data for the Archer's Post is summarized in Table 4.5.

The results show that around Archer's Post area, the potential evaporation is less variable from month to month as the area experiences permanent sunshine throughout the year.

Table 4.5 Evaporation Data in mm

Station Name MoWD No. Alt. (m)		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Max	Min	Annual
(a) ....1988 Pan Evaporation Data from Project Installed Stations																
Nundoto dam WD. 69	x	192	206	202	159	155	131	114	113	132	145	115	133	206	113	1797
1951	%	10.7	11.5	11.2	8.8	8.6	7.3	6.3	6.3	7.3	8.1	6.4	7.4	36.5		
Amaiya WD. 56	x	295	301	274	214	193	283	183	144	159	214	190	204	301	144	2654
1610	%	11.1	11.3	10.3	8.1	7.3	10.7	6.9	5.4	6.0	8.1	7.2	7.7	234	128	
S. Horr WD. 68	x	209	234	210	153	157	161	128	160	201	221	164	160	234	128	2153
1219	%	9.5	10.9	9.8	7.1	7.3	7.5	5.9	7.4	9.3	10.3	7.6	7.4			
Wamba WD. 57	x	203	215	219	216	164	1437	138	146	164	189	137	153	219	137	2087
1360	%	9.7	10.3	10.5	10.3	7.9	6.9	6.6	7.0	7.9	9.1	6.6	7.3			
(b) ....Average Monthly Pan Evaporation data at Archer's Post (1946-88)																
Archer's Post	x	270	269	286	222	239	260	275	287	292	281	213	232	292	213	3126
WD. 1	cv	0.15	0.11	0.14	0.20	0.17	0.11	0.12	0.10	0.09	0.11	0.18	0.21			
864	%	8.6	8.6	9.1	7.1	7.6	8.3	8.8	9.2	9.3	9.0	6.8	7.4			
(c) ....Penman estimate, mean monthly potential evaporation (Eo).. (1946-54)*																
Maralal	x	161	159	173	151	151	132	130	132	151	157	139	150	173	130	1786
1950 m	%	9.0	8.9	9.7	8.5	8.5	7.4	7.3	7.4	8.5	8.8	7.8	8.4			

Key: x = Monthly values
Cv = Coefficient of variation
% = Monthly values as percentage of annual total
* = From studies of potential Evaporation in Kenya by T. Woodhead EAAFRO 1968

The relatively lower values in April and November are associated with cloud cover as these months are in the middle of the rain seasons when it is relatively humid. On average, the highest evaporation is to be expected in september and the lowest in November.

The results of the analysis of the data for 1988 from the evaporation pan stations installed by the project are summarized in Table 4.5. Although these were based on one year's record, the results tend to conform to the expected pattern of monthly evaporation distribution.

During the year of observation the period of highest evaporation was in February at three of the four stations, the other one recording the highest in March. July, August, and November had the lowest evaporation.

The data from the four project installed stations only give some indication of the order of magnitude. If the stations installed by the project can be maintained for only a few more years, more reliable data on average distribution of monthly potential evaporation can be estimated for those areas.

Graphs for the monthly potential evaporation distribution are in Appendix 4.6.

4.5.3 Annual Evaporation

Annual potential evaporation data from class A pan for the Archer's Post area is summarized in Table 4.6. The annual potential evaporation for Maralal area as estimated by Woodhead and the 1988 data from the four project installed stations is in Table 4.5.

The average annual pan evaporation for the Archer's Post is about 3106 mm (based on 1946-88 data). It is less variable from year to year as indicated by the low coefficient of variation of 0.098.

Table 4.6 Annual Pan Evaporation Data at Archer's Post

Station No. ..... WD. 1 Latitude ... 00 38 20 N
Altitude ..... 864 m Longitude .. 37 39 50 E

Year	1946	1947	1948	1949	1950	1951	1952	1953	1954	1955	1956	1957	1958	1959
Amount (mm)	3325	2933	3248	3052	2694	2459	2894	2979	2826	2927	2706	2657	2740	*
Year	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973
Amount (mm)	*	2833	2711	*	3036	3494	*	3100	2710	3077	3670	3486	3504	3459
Year	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987
Amount (mm)	3362	3466	*	3265	3224	*	3532	3124	3172	*	*	3266	3325	3372

Years of complete record	= 34
Annual average	= 3106
Annual Maximum	= 3670
Annual Minimum	= 2459
Variation coefficient	= 9.8%
Incomplete record	= *

In Samburu District, as in many other regions, potential annual evaporation is expected to be generally a function of altitude. Low lying areas such as the Archer's Post area, Amaya etc will experience higher evaporation losses (3106 mm - pan data, Archer's Post).

Highland areas such as the Mathews range, Poror, Maralal will experience relatively less evaporation losses (1786 mm - Penman estimate, Maralal).

There is scarce data on evaporation in the district. To estimate for evaporation losses in areas where no data exists in the district, an approximation could be made by use of the relationship developed by Woodhead (1968) on the relationship between altitude and potential annual evaporation from open water surfaces. This is as given below:

$Eo = 2432 - 0.358h$

$r^2 = 0.66$

where: Eo = Potential Annual Evaporation in mm
h = altitude in m
n = number of observations
r = correlation coefficient

4.6 Surface Runoff

4.6.1 Description of the Surface Drainage System

Samburu district lies on the eastern shoulder rim of Kenya's rift valley. In the southwest are the broad volcanic highlands of the Leroghi plateau and Poro hills. The Karisia hills form a Basement ridge running north-south between the Leroghi Plateau and the Central Basin.

The Central basin is thought to have been an ancient lake formed by the drainage of the Leroghi Plateau. The district is a continuous basin sloping northwards to Lake Turkana and eastward to the Mathews Range.

In the southwest the altitude of the plains is about 2,000 m. The central plains are between 1,000 - 1,500 m, whereas the eastern and northern plains are between 500 - 1,000 m.

There are two major river systems thought to have resulted from continuous long periods of erosion which lowered the continuity of the plateau and drained the lake basin. The two are the Seiya - Milgis - Barsaloi system in the central basin and the Ewaso Ngiro system, Kenya's third longest river which forms the southern boundary of Samburu district. Both rivers flow eastwards. The Seiya -Milgis - Barsaloi system drains the Leroghi plateau and the central basin. It is fed by many ephemeral streams from Karisia hills, the Mathews range and the Ndoto mountains. The catchment covers about 30% of the whole Samburu district. The perennial Ewaso Ngiro originates in the mountains in and around Laikipia district and it is fed by ephemeral streams from the south eastern part of Samburu district. There are numerous dry water courses (laggas) some of which carry tremendous volumes of water during the rains. In spite of this, after the floods have passed, water is only found at shallow depths in the lagga beds.

The Wamba river originates from the Mathews range and flows southwest to the Ewaso Ngiro river. It is perennial only in the upper reaches high in the rugged mountain terrain. For much of its downstream course, it becomes intermittent only containing flowing water during and a few days after the rains.

In the extreme southwest of the district, there is the Amaya stream. It originates from the eastern side of the rift valley. It is thought to be probably connected with a deep groundwater table below the Leroghi plateau. The stream is perennial with a well defined channel but meanders slightly. It is a tributary to the upper Suguta drainage system.

The South Horr stream originates from the mount Nyiro and flows eastward past the South Horr centre towards Marsabit district. It is of limited catchment and in dry periods, the flow dwindles quickly as it flows south-eastwards.

In the western side of Mount Nyiro, there exists a small stream called Tuum. It flows westwards and it is said to be perennial only in the upper reaches near the source. In dry periods, it ceases to flow a short distance downstream of the forestry office in Tuum.

Much of the district is thus drained by numerous laggas of varying sizes most of which flood during the rains and cease to contain water shortly after the rains.

4.6.2 Runoff Data

Data Availability and Measurements

Runoff data in Samburu District is very scarce. Apart from the data on the Ewaso Ngiro river at Archers Post, no other runoff data of sufficient length and continuity exists. The estimation of the reliability of the existing few perennial streams such as the South Horr and Amaya as water sources is difficult at the moment.

Although the two streams are said to be perennial, their critical low flows in dry periods is unknown. Before the project moved in, no runoff data on daily water levels existed on the two. The project established regular gauging stations on the two streams and has continuous records of water levels from late 1987. Monthly discharge measurements have also been regularly taken. These discharge measurements have been used to prepare provisional rating curves for the stations. The ratings have been used to estimate the discharges during 1988 for the two streams.

The Ewaso Ngiro basin upstream of the regular gauging station number 5E3 at Archer's Post was studied in WRAP II, Laikipia District water resources investigations. Details of the runoff characteristics of the Ewaso Ngiro river at Archers' Post are contained in this report (Ministry of Water Development, 1987).

Bauwa Springs

The discharge measurements that have been made at the Bauwa springs near Bauwa Primary School are presented in table 4.7. The results show that the spring has poor yield (0 to 20 l/sec.). The spring ceases to flow in dry periods and most of the time it flows, the discharge is very low. The spring is therefore an unreliable water source.

Kichichi Stream

The discharge measurements taken on the Kichichi stream are summarized in Table 4.8. These were taken at the road crossing to the Kichichi lodge, downstream of the lodge.

Although during the 1988/89 period the stream never dried, local inhabitants state that in prolonged drought periods, it ceases to flow. Discharges measured ranged from 0.020 cubic metres per second in January 1988 to 1.649 cubic metres per second in April 1988.

Table 4.7 Flow Measurements, Bauwa Spring

Date	Discharge		Date	Discharge	
	l/s	m3/d		l/s	m3/d
16/10/70	0.45	39	15/05/89	0.17	15
26/11/70	0.45	39	11/74	0.36	31
17/10/73	0.20	17	12/74	0.02	2
06/02/74	0.06	5	12/74	0.36	31
14/02/74	0.01	1	06/75	0.00	0
18/02/74	0.74	64	06/75	0.23	20
16/03/74	0.00	0	14/06/88	15.4	1331 *
30/03/74	3.58	309	22/09/88	9.0	778 *
07/04/74	0.35	30	05/11/88	10.0	864 *
30/04/74	3.58	309	15/05/89	20.0	1728 *

Source: MoWD
Note: l/s = Litres per second
m^3/d = Cubic metres per day
* = Measurements taken by WRAP

This suggests that it carries substantial flow only during the rain months. The flow drops drastically in periods of less rain and if dry conditions are prolonged, it dries. Therefore without some storage, it can not be a reliable water supply source all the time.

Table 4.8 Flow Measurements, Kichichi Stream

Date	Discharge		Date	Discharge	
	l/s	m3/d		l/s	m3/d
20/01/88	20	1,728	08/11/88	71	6,134
28/04/88	1,649	142,474	29/01/89	106	9,158
08/06/88	132	11,405	09/03/89	23	1,987
13/07/88	90	7,776	12/05/89	890	76,896
14/09/88	30	2,592			

Source: Water Resources Assessment Project

Note: l/s = Litres per second
m^3/d = Cubic Metres per day

Tuum Spring

Discharge measurements taken by the project on the Tuum spring are summarized in table 4.9. These were taken near the Tuum forestry office some 30 m above the intake.

Interviews with the local people showed that the flow is perennial upto some short distance downstream of the forestry office beyond which the flow ceases in dry periods.

As it does not dry up in the higher reaches, an intake located high enough could be relied on to supply some water. However, the quantity of water to be expected from this source in dry periods is very small as indicated by the low discharges measured during the dry periods.

Table 4.9 Flow Measurements, Tuum Spring

Date	Discharge		Date	Discharge	
	l/s	m3/d		l/s	m3/d
09/10/87	1.1	95	16/07/88	80	6,912
09/11/87	1.6	138	16/09/88	5	432
03/12/87	0.5	43	06/11/88	5	432
18/01/88	3.0	259	31/01/89	5	432
25/02/88	2.0	173	12/03/89	4	346
02/05/88	7.1	613	16/05/89	3	259
11/06/88	4.1	354			

Source: Water Resources Assessment Project

Note: l/s = Litres per second
m^3/d = Cubic metres per day

Amaya Stream

Available data

The Amaya stream is perennial but no data existed on it before the project moved in Samburu District. A Regular Gauging station (RGS) was established at Amaya centre to monitor the flows. The data collected from October 1987 to March 1989 has been analysed to summarize the flow characteristics for the period of observation. The summary is in tables and graphs (see Table 4.10, and Appendix 4.12).

Rating Curve

To estimate the discharges from the recorded water levels for the period of observation, a provisional rating curve was prepared. This was based on discharge measurements taken between October 1987 and March 1989.

The rating curve was fitted by the least squares method. The equation used in the approximation was of the form:

log Q = log a + b log H. (For straight line rating curve on log - log scales).

where: Q = Discharge
H = Gauge height
a&b = rating constants

see appendix 4.12 for the rating curve.

Daily Discharges

Daily discharges were estimated by use of the daily water levels (gauge heights) and the provisional rating curve equation developed (Section 4.6.2.5.2).

In dry periods, the base flow varied between 14 to 22 litres per second (lps). The lowest daily discharge estimated was 14 lps. These were recorded in May and June 1988. The highest daily discharge estimated was over 5 cubic metres per second (cumecs) recorded in June (see Appendix 4.11).

Peak flows lasting between one to two days occurred on a few days between March and October. In most cases, the duration was only a day except in June when for two consecutive days, an estimated discharge of approximately 5 cumecs occurred.

A daily flow duration curve covering the period from October 11, 1987 to February 28, 1989 was constructed basing on estimated daily discharges (see Appendix 4.12). During this period, the estimated 96% daily flow for the Amaya was 14 litres per second.

Monthly Discharge

An estimate of total monthly flow distribution for 1988 was made. The lowest monthly discharge was in February and December (estimated as 51,000 cubic metres), and the highest in June (estimated as 956,000 cubic metres) (see Table 4.10).

During that year, June alone accounted for about 34% of the total estimated annual discharge. Substantial discharges are to be expected only in the months with higher rainfall on the catchment. In dry periods, the flow reduces very much.

Higher discharges on the Amaya stream are to be associated with rain days. Rainfall on this catchment occurs for a few days in most of the months. Expanded use of this source would require that some storage facility is made to store water for use in dry periods.

Annual Discharge

The annual discharge for 1988 was estimated as approximately 2.8 million cubic metres.

South Horr Stream

Available Data

Although it is perennial in the upper reaches, no data on continuous daily discharges existed. The project established an RGS to continuously monitor the flow. The data collected from November 1987 to March 1989 has been analysed for the flow characteristics during the observation period.

The estimates of discharges given for the South Horr and Amaya streams were based on data collected over a very short period (October 1987 - February 1989). The year 1988 was a wet year throughout the district (annual rainfall recorded was above annual average at all rainfall stations where records exist).

The monthly and annual discharges estimated for 1988 are therefore higher than the average flows to be expected.

Rating Curve

Provisional rating curve as for Amaya (see 4.5.2.5.2) was prepared for the station. Data used was from November 1987 to March 1989 (see Appendix 4.12 for the rating curve).

Daily Discharges

Daily discharges were estimated by use of the daily water level records (gauge heights) together with the provisional rating curve developed for the station.

The flow went very much down in dry periods. The lowest daily discharge estimated in 1988 was 5 litres per second (lps) observed in February. The highest (over 400 lps) was observed in April. The highest peaks occurred in April.

A daily flow duration curve covering the period between October 11, 1987 and February 28, 1989 was constructed (see Appendix 4.12). During this period, the estimated 96% daily flow for the South Horr stream was 6 litres per second.

Monthly Discharges

An estimate of the total monthly flow distribution for 1988 was made. The lowest monthly discharge estimated was 15,000 cubic metres in February. The highest was 190,000 cubic metres in April. About 37% of the estimated total annual flow was available only in the month of April (Table 4.10 and Appendix 4.12).

The erratic flow observed in 1988 is the typical flow regime of rivers in such an environment (semi-arid). The base flow was very small with higher discharges occurring only for a short period during the rains.

Future development of the South Horr stream as a water supply source would require some storage since the dry weather flow is very limited.

Table 4.10 Monthly Discharge in Thousand Cubic Metres, 1988

Stream		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Max	Min	Annual
S. Horr	x	37	15	20	290	63	40	70	57	49	50	50	53	290	15	794
	%	4.7	1.9	2.5	36.5	7.9	5.0	8.8	7.2	6.2	6.3	6.3	6.7	36.5	1.9	
Amaya	x	55	51	72	487	329	956	215	179	148	211	53	51	956	51	2807
	%	2.0	1.8	2.6	17.3	11.7	34.1	7.7	6.4	5.3	7.5	1.9	1.8	34.1	1.8	

x = Monthly Discharge
% = Monthly discharge as percentage of annual discharge

Annual Discharge

The annual discharge of the South Horr stream for the year 1988 was estimated as approximately 794,000 cubic metres.

Lagga Flows

Except for a few perennial stream water courses mentioned earlier, majority of the river water courses are laggas of varying sizes.

These laggas usually have sporadic, short isolated flow periods separated by longer periods of no flow. The peak flows result from high intensity rainfall. In some laggas, the peaks may occur within minutes of the start of the rise in discharge.

From the observations by the local inhabitants, the laggas are known to carry large

volumes of flood water during the rains. Shortly after the rains stop, the flow ceases. This may vary from hours to a few days for average years. In wet years, the duration of flow may last longer, sometimes for a whole month (see Table 4.11).

In some of the main laggas such as those in Illauti, and Wamba area, water may be available at shallow depths after rains stop.

It is difficult to quantify the total lagga flows by direct discharge measurements. This is due to problems associated with inaccessibility, suitable measuring sites and instrumentation.

Between November 1988 and October 1989 the project collected flow data on laggas by engaging observers to record the presence or absence of some flow in the laggas on a daily basis. This was done to give some indication of the flow duration in the selected laggas. The duration of flow is important as among other things it has some significance on possible recharge where the lagga beds are permeable.

Table 4.11 summarizes the total number of days some flow was available. Kichichi and Bawa Spring had 100% flow over the observation period. These have intermittent flow and will only dry up completely in prolonged drought.

At the other observation sites, the percentage of days with some flow for the observation period ranged from 15% at Baragoi to 78% at Tuum. The duration of flow depends on the rainfall patterns and other catchment characteristics such as the size, topography etc.

It should be noted that results summarized in Table 4.11 are based on a very short period of observation. This has also been a relatively wet period in most parts of the district where observations were made.

On the whole, laggas can only be useful as water sources if storage reservoirs are built where possible to store the flood water. Other possibilities that could be explored further are development of subsurface dams where conditions permit.

Table 4.11 Days with some flow in the Laggas and Springs

Name	1988		1989										Total Days	Days With Some Flow	% of Flow Days
	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct			
Wamba at Game Camp	4	10	31	22	0	21	27	30	30	12	0	0	365	187	517
Kichichi at road crossing to Lodge	30	31	31	28	31	30	31	30	31	31	30	31	365	365	100
Seiya at Lodokejek	13	17	0	0	11	6	31	30	24	31	20	11	365	194	53
Enkare Narok at road crossing to Kisima	30	6	0	0	0	3	31	18	15	31	28	31	365	193	53
Bawa spring Near Primary School	30	31	31	28	31	30	31	30	31	31	30	31	365	365	100
Baragoi at Pump House	10	2	0	3	8	11	8	0	6	0	2	4	365	54	15
Tum near Primary Sch.	24	31	0	10	12	22	31	30	31	31	30	31	365	283	78
Seiya at Suari	-	-	22	21	13	24	31	30	15	0	8	10	304	174	57
Nundoto Dam inflow	27	31	31	7	0	0	-	30	31	31	30	31	334	249	75
Nundoto Dam Outflow	30	0	0	0	0	19	-	19	15	31	30	31	334	175	52

The Nundoto Catchment

The Water Balance

The Nundoto reservoir situated in the Nundoto river catchment is the main water supply source for the Maralal township. The project installed a set of staff gauges to monitor daily changes of water levels since late 1987. Observations are made twice daily, in the morning and in the evening.

The catchment upstream of the reservoir is representative of the area covered by the Leroghi forest on the Karisia hills. Gauging sites elsewhere such as on the ephemeral Nundoto river which feeds the reservoir were not feasible due to risks of vandalism.

The daily water level observations in the reservoir have been used to estimate monthly changes in storage. The monthly storage changes have been used as one of the components of the water balance for the estimate of the surface water inflow into the Nundoto reservoir for the year 1988.

The water balance comprises of the following:

Inflow:	a	=	Surface water inflow
	b	=	rainfall on the reservoir area
	c	=	subsurface water inflow
Outflows:	d	=	Evaporation losses
	e	=	Seepage through dam embankment
	f	=	Outflow through the spillway
	g	=	Abstraction for the Maralal Water Supply

The major components are a, d, f, and g. The known components are b and d measured from facilities installed near the dam, f was estimated from the outflow across the spillway while g records were obtained from the water supply records. The surface water inflow, a, was estimated for each month in cubic metres.

To simplify the equation, the minor components c and e were excluded. The water balance therefore comprised of the other remaining components.

The computation of the surface inflow was estimated from the equation below:

$$I = 0 \pm ds.$$

where: I = Inflow (a and b)
0 = Outflow (d,f, and g)
ds = Change in storage volume

By substituting the various components in the equation used, it became as below:

$$a + b = d + f + g \pm ds$$

To estimate the only unknown, a, it was solved as:

$$a = (d + f + g \pm ds) - b$$

All the components were expressed as volume in cubic meters per month (see Table 4.12).

Evaporation Estimate

Estimate for the evaporation from the reservoir was based on the pan evaporation data collected for 1988. A pan coefficient of 0.9 was used. Computations were on daily basis then for each month, all daily values were summed.

Rainfall Data

Rainfall data from the raingauge located near the dam was used to estimate the rainfall volume over the reservoir surface for every month.

Abstraction from the Reservoir

Computation of monthly water abstracted for the Maralal water supply was based on records from the water supply records. Part of the time the meter did not function and therefore for those periods, only estimates (not based on meter) were supplied.

Spillway Discharge

To estimate the outflow through the spillway, some relationship was established between the water level in the reservoir and the spillway discharge. The relationship was based on only three current meter discharge measurements through the spillway. Due to the few measurements used, estimated discharges may tend to be on the higher side (overestimates).

Table 4.12 Nundoto Dam Water Balance for 1988

Month	Inflow (surface) (m^3)	Outflow (spillway) (m^3)	Direct rainfall (m^3)	Evaporation (m^3)	Water supply (m^3)	Volume change (m^3)
Jan	nil	nil	229	8001	16454	-23892
Feb	nil	nil	164	7572	14278	-21132
Mar	nil	nil	567	6730	17148	-23250
Apr	74758	nil	7821	4990	15484	62105
May	47599	nil	1526	6958	15096	27071
Jun	66884	nil	5443	6420	16427	49480
Jul	549432	485222	12391	6094	15593	54914
Aug	859420	850694	7697	6667	12541	-2785
Sep	797743	771638	8800	7791	13051	14063
Oct	480135	481075	3758	8463	12568	-18213
Nov	26790	13219	2507	6613	13584	-4119
Dec	20004	nil	3059	7666	14713	684
Annual	2922766	2601849	53962	83965	176937	114926

Estimation of Surface Inflow (1988)

The surface inflow for 1988 was estimated by the water balance approach for the reservoir. This was done on a monthly basis.

The results are in Table 4.12. The runoff yield from the water balance is computed as 2.9 million cubic metres for the year 1988. Due to the errors in the estimate of the other components, especially the outflow discharge through the spillway, this value is likely to be an overestimate. The rating of the spillway was based on only three current meter discharge measurements.

The year 1988 was a wet year for the catchment area and it is therefore reasonable to assume that the surface runoff yield into the reservoir was at least above 2 million cubic meters. In order to improve on the estimate of surface inflow into the reservoir by the water balance approach, it is necessary to improve on the spillway rating and in the daily observations for the other components.

If reliable records are collected for varying periods (dry, average and wet years), a better estimate for the runoff yield of the Nundoto catchment above the reservoir may be achieved. It is therefore strongly recommended that hydrological monitoring be continued by the surface water Section of the MoWD when the project moves out of the district.

The data collected would facilitate yearly estimates of runoff to be made.

Estimation of Average Annual Yield from the Catchment upstream of the Reservoir

The Nundoto river that feeds the reservoir carries water during and shortly after the rains. When rains cease, the flow ceases after a short time (days or a few weeks).

An estimate of the average annual runoff yield basing on average rainfall at Mararal DC and Poror forest rainfall stations has been made.

In average years, the annual runoff yield may be estimated at between 1.5 to 2% of the average annual rainfall of the catchment. In the neighbouring Baringo district, streams in the humid parts were noted to have erratic flow with much of the runoff occurring during the rains. Basing on the runoff and rainfall data collected in those areas, the average annual runoff values ranged between 6 to 19% of the annual average rainfall.

The Nundoto river is ephemeral. The estimate of 1.5 to 2% runoff for average years is reasonable. On this basis, the average runoff yield may be estimated at between 452,000 to 600,000 cubic meters. The Nundoto catchment upstream of the reservoir is about 52 square kilometers. Average annual rainfall is about 580 mm.

In 1976, the Howard Humpreys' and Sons consulting engineers in their preliminary design report for the Maralal water supply estimated average annual runoff above the reservoir to be about 372,000 cubic meters. Their estimate was based on Richard's theory of determining runoff from rainfall for varying degrees of wetness.

However, in their report, they recommended further investigations on the runoff on the catchment to be undertaken.

Better understanding of runoff from a catchment is achieved by collecting and analysing hydrological data over a period of time. It is therefore strongly recommended that the surface water Section of the Ministry of Water Development continues with collection and analysis of data from the project installed hydrological stations, when WRAP finally leaves the District.

4.7 Surface Water Quality

The samples of surface water were collected from Nundoto Dam, Lake Turkana, the Ewaso Ngiro and from perennial streams at Amaya and South Horr. Samples collected at springs are described in paragraph 5.2.7. In total 11 analyses are available (Appendix 4.16).

The ionic balance calculations show that 4 analyses can be considered accurate. The other analyses though not accurate are still useful, because they indicate orders of magnitude of the various ion concentrations and may provide information on the water suitability.

The sample from Lake Turkana shows the high salinity of this water body, which does not posses a drainage outlet. The water from the lake is not suitable for drinking purposes.

The sample from Nundoto Dam indicates the necessity of the present treatment plant, through which the water is supplied to Maralal town. The water in the reservoir has a high turbidity and contains a lot of organic matter. The high iron concentration probably is related to the lateristic soil type around the reservoir.

The samples from the perennial streams at Amaya and South Horr show the different rock formations from which the springs feeding the streams originate. At South Horr the Nyiro mountain consists of Basement rock and the water is slightly acidic, with a low degree of mineralisation. At Amaya the spring is located in volcanic rocks and the water is slightly alkaline, mildly saline. The water from both streams is suitable for domestic consumption, but chlorination and filtration is necessary to ensure a continuous safe water quality.

The samples from the Ewaso Ngiro show a high turbidity. However the water is suitable for domestic use after treatment.

The surface water samples are generally of the sodium-bicarbonate type. Fluoride concentration in excess of the WHO-guideline value (1.5 mg/l) is only found in the Lake Turkana water.

The water at Amaya and at South Horr is currently used for small scale irrigation. At Amaya however the salinity level and a high Sodium Adsorption-Rate value (SAR) indicate that salination and degradation of the soil may occur with time.

5 HYDROGEOLOGY

5.1 Previous Hydrogeological Studies

Most geological reports (Chapter 2) contain a section or a chapter on water supply or water resources. However, only general conclusions on groundwater conditions are presented, as rocks rather than water is the main interest of these reports.

The conclusions of the most relevant reports are briefly outlined below.

Geology of the Country between Nanyuki and Maralal (Shackleton, 1946): In the Basement System, granitoid gneisses are regarded as unfavourable whereas more biotitic zones offer a better hope of success, as do the pelitic gneisses. The pelitic gneisses probably offer the best chance of successful boreholes as they are a variable series of easily decomposed rocks which should yield water readily. Borehole statistics (according to Shackleton) show a success rate of about 70% for boreholes in the basement country in Kenya but in the study area it is only 50%. This low figure is due to the fact that most holes are in the Loldaikas (Laikipia) where conditions are difficult. The prevailing rock there is granitoid gneiss which is regarded as unfavourable. The larger north-south valleys coincide with the relatively soft biotitic zones. Places in line with the main ridges which usually consist of these granitoid gneisses, should be avoided. The Red Sandy Earths covering the Basement System Rocks are all so porous that percolating water must drain rapidly downward to the water table which lies usually within the underlying metamorphic rocks. It is unlikely that shallow boreholes would be successful in these earths, except perhaps where they merge into alluvial cones at the mouth of some of the valleys which drain the higher hills. Information on the Rumuruti Phonolites (which underlie the Leroghi Plateau and the plateau north of Maralal) comes mainly from Laikipia where 75% of the boreholes were successful (according to Shackleton). It is concluded that the chances of getting water from properly sited boreholes in Northern Laikipia (and Leroghi, etc) are good.

Geology of the Baragoi Area (Baker, 1963): The principal sources of groundwater are wells, seepages and springs in the sandy beds of rivers. Seepages are common in the lower reaches of the Baragoi river where hard impervious rocks floor the river bed. Along the Ayena Aturkon river (west of Baragoi), which is underlain by fractured olivine basalts, only a few waterpoints are present. At the base of the escarpment, on the east side of the Suguta Valley, are a number of slightly saline seepages. Further north there is a hot saline spring at Elboitong.

Geology of the South Horr Area (Dodson, 1963): Water is obtainable at three streams on the eastern slopes of the Ol Donyo Nyiru and from the Tuum spring and a stream on the western slopes, even during the driest months of the year.

Geology of the Kauro - Merille Area (Rix, 1963): Water is held in the sandy beds of the Kauro and Merille systems. There are a number of points along these lagas where the supply is permanent, e.g: Kauro, Serolepi, Kinya, Lenkaya, Kapai and Sera.

Geology of the Maralal Area (Key, 1987): Perennial supplies of surface water are confined to the upper reaches of water courses in the Karisia HIlls and the western part of the eastern shoulder of the Rift Valley. These include the Logolin, Moridjo,

Nashoda, Parasoro and Tauka Rivers in the volcanic terrain and the Loikas, Lalu, Ndadapo and Yamo Rivers in the Karisia Hills. The rivers are fed from cold springs. Future boreholes into basement rocks should always penetrate more than 60 meters and avoid the massive migmatites and granites. There appears to be a good supply of groundwater (of uncertain quality) throughout the gneisses. Obvious targets for high yields are the major fracture zones, especially where they intersect or are followed by large water courses. Boreholes on the volcanic terrain should either penetrate to basal sediments or gneiss basement, or intersect weathered or porous horizons in the volcanic succession, such as basaltic lavas, various tuffs or sediments.

Geology of the Laisamis Area (Charsley, 1987): There are traditional perennial water holes in places along the Milgis-Barsaloi, Seiya, Merille, Kauro and some tributaries of these rivers. Aquifers in the metamorphic rocks are invariably limited in extent. They are confined to strongly weathered horizons and fractures, which may also be the fronts of weathering. Shear zones and major fractures, close to where they transect active drainage channels, best prospects for high yields.

Geology of the Isiolo Area (Hackman et al, 1989): The granite gneiss complexes such as the Mathews ranges are poor in groundwater availability: favourable areas are the infilled north-south basins, which are usually underlain by the softer, more biotitic zones of gneisses and amphibolitic gneisses. In general, areas with high relief should be avoided due to lack of deep weathering and jointing.

5.2 Available Data

5.2.1 Aerial Photographs and Landsat Data

The District is covered by three scenes of landsat MSS imageries viz;path 180 row 059 and 060 and path 181 row 59, all on a scale of 1:250,000, and three scenes of TM imageries, path D169 rows 058 - 059, and path D168 row 058. In this study exclusively false colour composites of these imageries were used.

The area has also been photographed from a low platform (though not wholly). There are 370 photos on a scale of 1:50,000 distributed over twenty flight lines. Interpretation of these photographs has been very useful in choosing suitable areas for geophysical surveys in the Basement system.

5.2.2 Boreholes

By the time of writing the report, the records of 73 boreholes were available in the district. More boreholes might have been sunk but it is likely that a number of dry holes were never reported to the MoWD. The current data show a failure rate of 16% but it is likely that the actual failure rate is about twice as high. A summary of the borehole data is given in Appendix 5.1. Most of the boreholes are confined to the bigger centres (see Plate 5.1).

Sixteen boreholes were drilled within the framework of the WRAP study. The choice of the drilling sites was mainly based on water demand, but geophysical and hydrogeological considerations were also taken into account.

5.2.3 Shallow Wells

The shallow wells in this area are normally dug along the dry river beds (laggas) in the Basement areas in order to tap the subsurface flow in them. In most areas this is the only source of water. These wells are normally of a large diameter and their depths depend on the position of the water table.

It is difficult to quantify the number of dug wells in the district because there are many lagas with difficult accessibility for surveying. Moreover their number changes substantially with the seasons and corresponding demand for water. Most of these wells get filled up with sand during the rains and the local people may or may not re-dig them in the same positions after the rains. A few, however, are protected by masonry work from such events.

5.2.4 Springs

Springs with a reasonable flow of good clean water emanate from the mountain ranges, namely the Nyiro mountains, Ndoto mountains and the Mathews Range, at points or zones where the metamorphic rocks are heavily fractured, fissured or faulted. Springs that occur in the volcanic regions are poorer both in flow and in quality except for the Amaya stream, whose catchment is largely outside the district.

Some springs rise from high up the mountains in densely vegetated areas and their sources were not accessible. Sampling and other measurements were in such cases done at the highest upstream points possible.

The tables below shows the general water quality of the perennial springs:

Table 5.1 Springs of the Metamorphic (Basement) area:

Name	Total Dissolved Solids (mg/l)	Mean TDS (mg/l)
Bauwa	335	
Barsaloi	351	
Ngurunit	123	175
Arsim	157	
Tuum	210	
Kurungu	111	
South Horr	71	
Kichich	44	
Opiroi*		
Wamba*		

* Analysis not available

Table 5.2 Springs of the Volcanic area:

	Total Dissolved Solids (mg/l)	Mean TDS (mg/l)
Amaya	400	
Sukuta Marmar	480	440
Kirimun*		

* Analysis not Available

More chemical data on springs is given at Appendix 5.2.

Table 5.3 Groundwater Level Fluctuations

Borehole No.	Location	Date	Water Rest Level (m) (Below Surface)
C5898	Loikas	06/09/84	4.70
		14/01/88	4.20
		20/02/88	3.96
		01/05/88	4.35
		12/07/88	4.05
		12/08/89	4.29
		11/11/89	4.31
		03/03/90	3.50
C4895	Maralal	15/11/81	18.75
		14/01/88	17.84
		20/02/88	17.87
		01/05/88	17.21
		15/07/88	16.80
		19/09/88	16.14
		12/07/89	16.45
		12/08/89	17.00
		11/11/89	17.58
		03/03/90	15.90
C6796	Wamba	00/08/85	42.90
		21/01/88	40.32
		17/02/88	40.68
		17/04/88	39.40
		13/07/88	41.05
		14/09/88	38.86
		12/07/89	36.89
		12/08/89	37.30
		04/11/89	43.18
		25/02/90	32.71
C3565	Serolevi	22/01/88	10.88
		17/02/88	9.87
C3599	Serolevi	27/05/69	10.60
		22/01/88	11.90
		17/02/88	10.50
C7916	Swuari	14/07/88	62.90
		12/07/89	54.21
		12/08/89	54.00
		05/11/89	56.31
		25/02/90	53.73
C7917	Kowop	09/12/88	55.90
		/07/89	54.97
		12/08/89	54.51
		06/11/89	58.85
		27/02/90	56.27
C7918	Barsaloi	02/02/89	9.50
		12/07/89	9.23
		12/08/89	9.35
		28/08/89	5.22
		05/11/89	9.31
		25/02/90	9.17
C7919	Masikita	26/01/89	5.50
		12/07/89	4.33
		12/08/89	4.76
		07/11/89	5.21
		26/02/90	4.01
C7922	Nundoto	08/05/89	13.50
		12/07/89	8.23
		12/08/89	7.97
		28/08/89	6.99
		10/11/89	6.24
		01/03/90	5.90

5.2.5 Groundwater Levels and Fluctuation

The data on water struck levels and water rest levels from the archives of the MoWD is tabulated in Appendix 5.1. The water struck level refers to the depth at which water was encountered during the drilling works, whereas the water rest level refers to the final level to which the water rose or fell after it was struck.

Generally water rest levels rise above the struck levels indicating that the aquifers are mainly of the confined type.

The depth to the aquifers ranges between 2 metres (C3624, Merille) and 123 metres (C7917, Kowop) in the Basement areas; and between 26 metres (C7921 Losuk) and 169 metres (Lonkewan) in the volcanics. Mean water rest levels in the two areas are 25 and 50 metres respectively.

Regular monitoring of groundwater levels from boreholes in the district has not been carried out. However some data exists for boreholes whose static water level measurements have been taken during the study period. From the available data (Table 5.3), it is apparent that the groundwater level fluctuations correspond to the seasonal variations in rainfall. It is however not possible at this stage to predict the long term effect of pumping of the aquifers until longer term monitoring of the static levels is accomplished. However, it is likely that the effect is negligible given the low current rates of abstraction.

5.2.6 Well test data

Data on tested yields are available for 63 boreholes in Samburu including the ones drilled by WRAP. These tested yields should be considered only as first, rather rough estimates of sustained yield: drawdown is not recorded (except in three cases) and so the effect of pumping on the waterlevel in the borehole cannot be assessed.

Records of three pumptests are available at the archives of the MoWD. A pumptest can be defined as a test when both pumping and its resulting drawdown are recorded. However, quantitative interpretation is difficult because of very unstable pumping rates in all three cases. Therefore, no attempts were made to analyze these tests.

The WRAP pumping test unit has carried out eleven step drawdown tests in Samburu, in all boreholes drilled by the WRAP drilling rig which struck water. The WRAP test usually begins with a step-drawdown test which proceeds into a traditional pumptest. The step-drawdown test is carried out to assess well losses. After this, pumping should continue for up to 24 hours when pumping is stopped. The recovery is used to estimate transmissibilities.

However in many tests this schedule could not be maintained and test has to be shortened. Several problems were encountered, notably during the first tests because of lack of experience and established procedures: e.g. unstable pumping rates and mechanical problems with the testpump unit. In one case (Ledero, C7915) pumping rates dropped dramatically during the late night-early morning hours as a result of an unexpected sharp drop in water levels at that time.

The pumptests are shown in Appendix 5.4 which also includes a table containing the results of the calculations and a description of the procedures followed. Short discussions on the results are included in section 5.5.

5.2.7 Chemical Data

The results of all available analyses of groundwater samples collected from 16 boreholes, 10 springs and 9 wells are listed in Appendix 5.2. A total of 35 analyses are

available. The ionic balance of 19 analyses is within 5% and 29 analyses within 10%. The accuracy of these samples can be considered acceptable. Despite possible laboratory errors, the other samples are still useful as they indicate orders of magnitude of the various ion concentrations.

5.3 Hydrogeological Investigations

These have been carried out in four stages.

- inventory of existing data.
- remote sensing techniques.
- field techniques.
- exploratory drilling.

The first stage has already been discussed in paragraphs 5.1 and 5.2. The other stages are discussed below.

5.3.1 Remote Sensing Techniques

At the outset of the study little was known about the hydrogeology of the area. It was therefore necessary to get additional information on water aspects as well as particulars regarding the conditions of the environment in a short time. A useful technique to get this information is remote sensing. The methods used were:

a) Interpretation of false colour composite Landsat pictures on a scale of 1:250.000.
b) Stereoscopic interpretation of aerial photographs.

Interpretation of aerial photographs was useful in determining sites for detailed geophysical field investigations which in turn led to selection of sites for drilling.

5.3.2 Field Techniques

These entailed a ground geological survey to check on structures that were mapped on aerial photographs, geophysical surveys (see Chapter 3), collection of water samples for chemical analysis and in situ drilling sample description.

5.3.3 Exploratory Drilling

Sixteen boreholes were drilled in the district during the study programme. Fourteen of them were drilled in metamorphic rock areas while two were drilled in the volcanic rocks of Leroghi plateau. The priority for drilling was, however, given to areas with high water demand.

Given in the table below is a summary of the drilling results:

Table 5.4 Boreholes Drilled during the WRAP Study Programme.

BH NO.	Location	Total Depth (m)	Water Struck Level (m)	Water Rest Level (m)	Tested Yield m3/hour	TDS mg/l	Fluoride mg/l
C7908	Ledero (rig test)	80	-	23.6	1.2	389	0.7
C7909	Wamba	93	14	9.6	Dry	-	-
C7910	Wamba	120	26,68	9.0	1.2		-
C7911	Wamba	80	52	27.3	3.2	2100	2.0
C7912	Namanyarobo	100	-	-	Dry	-	-
C7913 (a)	Kimaniki Pass	64	-	-	*Dry	-	-
C7913 (b)	Kimaniki Pass	92	-	-	*Dry	-	-
C7914	Lengusaka	70	18	2.9	1.1	1740	2.5
C7915	Lengei	100	54,63	39	1.8	1200	0.9
C7916	Swuari	130	70	63	2.8	5184	0.8
C7917	Kowop	160	123	56	2.0	2120	3.0
C7918	Barsaloi	40	16	9.5	7.2	356	1.1
C7919	Masiketa	100	16,70	5.5	5.2	933	1.8
C7920	Kirisia	160	34	33	**Abandoned	-	-
C7921	Losuk	100	26,58	1.2	12	432	1.0
C7922	Nondoto	200	112	13.5	6	612	7.0

* Collapsed before striking water
** Tested yield: ca 1 m^3/h

5.4 Groundwater Occurrence

Groundwater in Samburu District can be found under the following conditions:

(i) Volcanic Area:

- old land surfaces interbedded between lava flows
- fracture zones, faults

(ii) Basement System:

- contact zones with intrusions
- weathered and/or fractured zones in pelitic Basement
- fractured zones in granitic Basement
- alluvial and colluvial deposits covering Basement

5.5 Groundwater Zones

Based on geology and general aquifer conditions, the district may be divided into two broad hydrogeological zones:

(a) Zone I - the volcanic rock area (covering the western part)
(b) Zone II - the metamorphic rock area (covering the rest of the district)

Zone I is further divided into two subzones, Ia, Ib while zone II is divided into four subzones, IIa through IId according to the nature of the rocks. Four other subzones, IIA though IID, based on the nature of superficial deposits (alluvium, colluvium) or the geomorphology (Basalt caps, mountain ranges) are superimposed on the afore mentioned Basement units.

The distinguishing characteristic for Zone I is a regional aquifer system while Zone II has a local aquifer system. The aquifer system for the latter is evident from the available borehole data. There are large variations in transmissibility and hydrochemistry over short distances. However for Zone I it is not possible to map out the aquifer systems in the two subzones because of lack of data. The conclusion that a regional aquifer system exists here, is mainly based on comparison with hydrogeology of similar volcanic rocks elsewhere, particularly in the neighbouring districts of Laikipia and Baringo. Water Resources Assessment study in Laikipia District, MoWD, 1987, and Water Resources Assessment Study in Baringo District, MoWD, 1987).

For a summary of the most important aquifer properties, reference is made to Table 5.8 while the areal distribution is shown on Plate 5.1.

5.6 The Regional Aquifer System (Volcanic Rock Area, Zone I)

5.6.1 General Description

About one-third of the district is covered by volcanic rocks. The area mainly covered by these rocks is the western part of the district. It is this area that has been considered under Zone I. Isolated patches of lava flows occur elsewhere in the district but due to their small areal extent and their thinness, they have been hydrogeologically considered as a separate subzone in zone II.

Only two boreholes in the volcanic aquifer were tested: those at Losuk and at Nondoto. The time-drawdown and recovery curves of the Losuk borehole (C7921) plot as rather straight lines on semi-logarithmic paper. After every step, the slope of the time-drawdown curve is nearly parallel to the slope of the previous phase while the recovery plots as a straight line (on a logarithmic time scale) after about 10 minutes. This suggests that groundwater flow regime follows the rules of linear flow in an extensive aquifer: it is compatible to the concept of a cone of depression which is free to expand a really in an extensive aquifer. The same type of curves are usually found in extensive sedimentary basins of moderate to good permeability. The Losuk borehole draws water from Old Landsurface deposits (cinderlayers, ash, murram) with a total thickness of about 15 metres. Such Old Landsurfaces are known to be usually good aquifers and to have a large areal extent.

The Nondoto (C7922) borehole draws water from weathered clayey volcanics. No signs of Old Landsurface deposits appears in the lithological log. Permeability is low.

Use of the equations derived from the step-drawdown part of the test probably gives misleading results as the main assumption (i.e that the response of the borehole and aquifer can be split up into a linear and a nonlinear part with behaves like a power curve) is questionable. Therefore, the sustained yields are estimated, rather arbitrarily, by eye with as the main criterium that drawdowns must still be acceptable after 24 hours of continuous pumping.

The area was subdivided into two subzones which are described below:

5.6.2 Subzones of the Regional Aquifer System

Subzone Ia: Leroghi and Marti Plateau Phonolites

The geology of Leroghi plateau area is phonolites (phonolitic lavas and tuffs) of the Upper Miocene, underlain by other trachyphonolitic lavas and tuffs of the Middle Miocene, Basaltic pyroclasts and lavas of Lower Miocene and metamorphic rocks of the Basement system. There were time breaks in between the various flows as well as the Basement/volcanic contact zone. Consequently good aquifers are found within these old land surfaces. The rocks are also faulted and fractured at various localities.

The Marti Plateau consist of phonolites (phonolitic lavas and tuffs) overlying basalts. The whole area is underlain by the granitic Leroghi gneisses.

The Leroghi plateau has the highest altitude in Zone I and receives higher rainfall than the rest of Zone I. Annual average rainfall is about 600 mm. The Marti Plateau receives a mean annual rainfall of about 500 mm.

One borehole drilled at Loosuk (C-7921) gave a yield of 12 m^3/hour. This may be an example of a good yielding borehole due to its location in a fracture/fault zone where good recharge into the ground is available. Other sites of good fracture and good catchment in this subzone should provide reasonable yields particularly if the borehole penetrates through old land surfaces.

Two boreholes were drilled near Marti. C-1553 was drilled in 1951 into the phonolites and gave a poor yield of 0.68 m^3/hour. The other borehole No. C1639 which has been drilled in the same locality penetrated a metamorphic formation, (Appendix 5.1) according to the records. However, the records are probably erroneous as the geological maps show the occurrence of volcanics. This was confirmed by inspection on the site. Therefore, this borehole was classified as volcanic. Its yield is 4.3 m^3/h.

The quality of groundwater from this subzone is generally good.

Table 5.9 below, shows some data on the 8 boreholes which have been drilled in this subzone.

Table 5.6 Boreholes in Zone I

BH NO.	Location	Total Depth (m)	Water Struck Level (m)	Water Rest Level (m)	Tested Yield m3/hour	TDS mg/l
C1553	Marti	136	70	59	0.68	-
C1639	Marti	102	69	60	4.3	-
C2434	Longewan	183	169	146	2.5	546
C2847	Longewan	180	110	71	2.1	-
C2972	Lonkewan	259	46	49	1.2	-
C3833	Sirata Oirobi	123	38	1	2.2	395
C7921	Loosuk	100	26	1.2	12	432
C7922	Nondoto	200	112	14	6	612
Mean			80	52	3.9	496

More analysis of the borehole data is given in Appendix 5.

Table 5.5 Summary on Groundwater Subzones

	SUBZONE	GEOLOGY	TYPE OF AQUIFER OCCURRENCE	RECHARGE/DISCHARGE CONDITIONS (ANNUAL RAINFALL)	DEPTH TO FIRST WATER STRUCK LEVEL AVERAGE (RANGE) M	DEPTH TO WATER REST-LEVELS AVERAGE (RANGE) M	YIELD PER BOREHOLE AVERAGE (RANGE) M^3/HR	GENERAL WATER QUALITY MEAN TDS MG/L
	Ia. Leroghi Plateau	Phonolites	Regional: weathered zones old land surfaces, fractures.	Mainly recharge (600 mm)	80 (26-169)	40 (1-71)	4 (0.7-12)	Good ~500
	Ib. Western Strip Volcanics	Basalts, phonolites, tuffs, trachytes	Regional: faults/fracture zone weathered zone, old land surfaces	Little recharge, little discharge (400 mm)	very deep (due to faults)	deep	Not known probably low	No Data (probably fair to poor)
	IIa. Pelitic and Semi-Pelitic	Pelitic to semi-pelitic gneisses, schists.	Local: faults, fractures, weathered zone	Some recharge (400 mm)	40 (12-123)	28 (8-56)	3 (0-10)	Fair to poor ~3500
	IIb. Granitic or Migmatitic	Granitoid gneisses, Migmatites	Local: faults, fractures	Some recharge (200-400 mm)	50	17	low yields 1.5	Fair to poor 2500
	IIc. Undivided	All types of Basement Rocks	Local: faults fractures weathered zone	Some recharge (400 mm)	50	25	2	Fair to poor
	IId. Intrusives	Pink granites pegmatites	Contact zone	Some recharge (400 mm)	Variable	Variable	8	Good to fair ~1000
	IIA. Sediment cover on Basement	Colluvium, alluvium gneisses, schists pegmatites	Local: colluvium/alluvium infilled basins, weathered zones, faults, fractures	Some Recharge (400 mm)	10 (2-100)	11 (2-100)	6 (0-22)	Good to fair 1000
	IIB. Basalt Caps on Basement	Olivine basalts, nepheline basanites sediments, gneisses, Schists.	Local: sediment/weathered zone, fractures	Some Recharge (300 mm)	Deep (due to erosion around cap)	Deep	No Data, probably low	No Data Probably fair to poor
	IIC. Mountain Range Areas in Basement	Granitoid gneisses, quartzofeldspathic gneisses, compact biotite granitic gneisses.	Local: fault/fracture zones	Some recharge + Transmission through faults/fissures to springs (500 - 1250 mm)	Deep (faults)	Deep	Very little yield expected	Good quality expected
	IID. Lagga Sediments on Base-ment	Sandy sediments-alluvial/colluvial deposits over mainly gneisses and schists.	Shallow, local, within alluvial sediments	Subsurface river flow; slow seepage through faults fissures into underlying rock	Only few metres	Only few metres	0.5 to 3	Good.

As can be seen from the above table, aquifers are struck at a mean depth of 80 m below surface while the water rest levels stand at a much shallower depth. The aquifers are of the confined type. Transmissibilities are in the region of 10 m^2/day. Groundwater potential in this subzone may be regarded as moderate.

The baseflow analyses carried out by WRAP (Water Resources Assessment Studies in Baringo District, MoWD 1987) suggest that about 3% of the annual rainfall can be considered as potential recharge for the uplands areas of Central Baringo. In the absence of adequate data, a conservative figure of 1%, and a safe (or recoverable) yield at 20% of the available recharge, are used for this subzone. It works out that for this subzone, with an area of about 1482 km^2 and annual rainfall of 600 mm, about 8.9 million cubic meters of water infiltrates into the ground of which 1.8 Mm^3/year can be withdrawn.

Average yield per borehole is 3.9 m^3/hr or 17,000 m^3/year for 12 hours per day of pumping. Therefore the available recharge can sustain approximately 100 boreholes.

Subzone Ib: The Western Strip Volcanics

The geology of the entire western strip of the district is volcanic; rock types being basalts, phonolites, trachytes and tuffs.

Besides the thin superficial deposits, the youngest rocks in this subzone are trachytic lavas and tuffs with minor basalt flows of Emuruangogolak, Emurua Giring, and Tirr Tirr. Other rocks are the Losiolo phonolitic lavas and tuffs, Kamolingalan basaltic lavas, tuffs and related sediments. Phonolitic and trachyphonolitic lavas and tuffs of Lopet plateau and Towana formation. Trachytic and phonolitic tuffs (with minor sediments and basalts) of Alengerr and Katomuk, all underlain by metamorphic rocks of the Basement System.

The rocks are heavily fractured and faulted, as a result of the movements that formed the Rift Valley. Many normal faults with downthrows to the east cut across the area, forming some escarpments. Other faults downthrow to the west, facing the Suguta trough. The amount of the westerly downthrows is however much greater than the easterly downthrows. The physiography of this subzone is the result of volcanicity followed by downwarping or volcanicity accompanied by faulting over time.

This subzone receives an average annual rainfall of about 400 mm. The area has good drainage via the many seasonal streams which mainly flow into the major Suguta valley to the west and some drain into other bigger seasonal rivers to the east of the subzone.

Exploratory drilling for water has not yet been carried out in this area due to poor accessibility. However, noting that the geology consists of permeable rocks like basalts and considering the heavy fracturing and faulting and low rains, aquifers of moderate yield would be expected. But, an effect of the faults and fractures is that groundwater flows to deeper horizons, towards the Suguta valley. Aquifer that get their recharge from the Suguta valley are likely to have poor quality water, due to the poor drainage and possible mixing with deep seated sources (hot saline springs etc.). Nevertheless, drilling in the deep canyons running towards the Rift Valley could be worthwhile.

Considering the structure, physiography and the low rainfall of this subzone, the groundwater availability here may be regarded as low: groundwater levels might be simply too deep.

The total area of this subzone is approximately 2845 km^2. Assuming available recharge to aquifers at a conservative 0.5% of rainfall, and 20% of this as the recoverable amount, it works out that about 1.1 million cubic metres of groundwater can be available from the subzone annually.

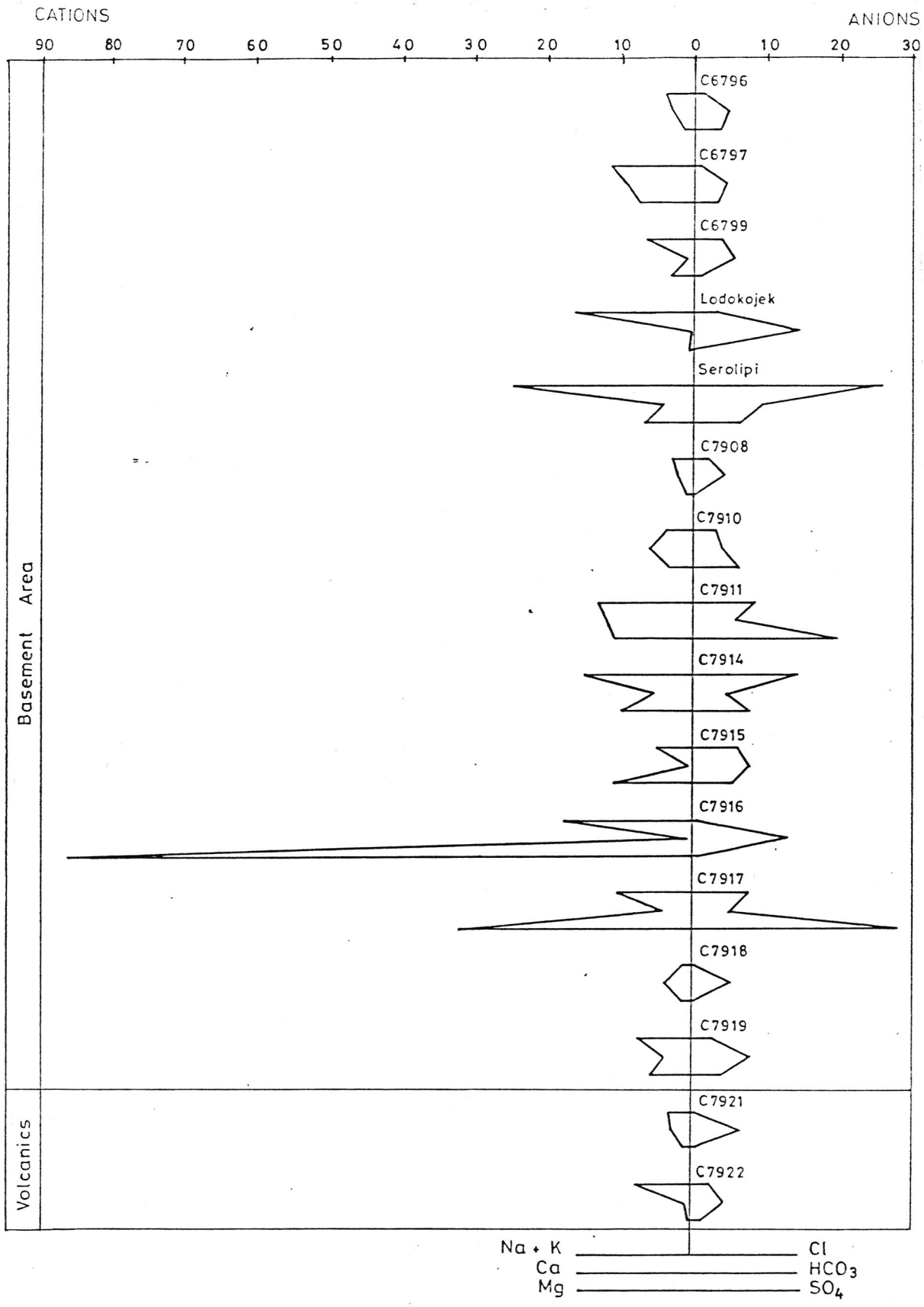


Fig. 5.1 Stiff Diagram of Groundwater Samples from Boreholes

5.6.3 Chemical Composition of Groundwater in the Volcanics

Only few data are available from watersources in the volcanic area: two chemical analyses from springs, nine from wells (Appendix 5.2 and Table 5.7) and only two from boreholes (Appendix 5.3 and Table 5.8). These analyses confirm the conclusion based on data from elsewhere in Kenya that quality of groundwater in the volcanics is usually good, suitable for domestic use and irrigation although fluoride can be a problem. That is why water from the Nondoto borehole (C7922) is not suitable for domestic use.

Water from the two sampled springs and the two sampled boreholes is of the sodium bi-carbonate type (Figure 5.1 and 5.2) while this type of water also dominates the samples taken in wells.

Table 5.7 Interpretation of Chemical Data (Springs)

Name of Spring	Meq/l							Ionic Balance %	Hydrogeological Zone: 1. Volcanic 2. Basement
	Na+K	Ca	Mg	Cl	HCO3	SO4	Sum of reacting values		
Amaya	2.03	0.08	0.06	0.14	6.39	0.17	8.87	-	1
Sukuta Marmar	2.21	0.05	0.04	0.39	6.20	0.42	9.31	-	1
Ngurunit	0.52	0.7	0.44	0.31	1.16	0.29	3.42	2.9	2
Arsim	0.43	0.7	0.48	0.39	1.20	0.27	3.47	7.2	2
Tuum	0.42	1.52	0.67	0.51	2.52	0.21	5.85	10.8	2
Kurungu	0.47	0.7	0.36	0.31	0.97	0.21	3.02	1.3	2
South Horr	0.16	0.40	0.28	0.17	0.72	0.15	1.88	10.6	2
Kithich	0.19	0.20	0.16	0.11	0.46	0.11	1.23	10.6	2

Table 5.8 Interpretation of Chemical Data (Boreholes)

B.H No.	Meq/l							Ionic Balance %	Hydrogeological Zone: 1. Volcanic 2. Basement
	Na+K	Ca	Mg	Cl	HCO3	SO4	Sum of reacting values		
C7908	2.57	2.06	1.23	2.06	4.68	0.35	12.95	9.5	2
C7911	13.38	11.96	10.86	8.77	6.00	19.78	70.75	2.3	2
C7914	15.22	5.29	10.21	14.56	4.82	7.79	57.89	6.1	2
C7915	4.98	0.45	11.44	6.21	7.93	5.58	36.59	7.8	2
C7918	1.39	3.73	1.40	0.71	5.60	0.54	13.37	2.5	2
C7919	7.54	3.68	5.51	3.24	8.43	4.37	32.77	2.1	2
C7921	3.19	2.70	0.99	0.59	6.77	0.23	14.47	4.9	1
C7922	7.83	0.88	0.40	2.85	4.88	1.54	18.38	0.8	1

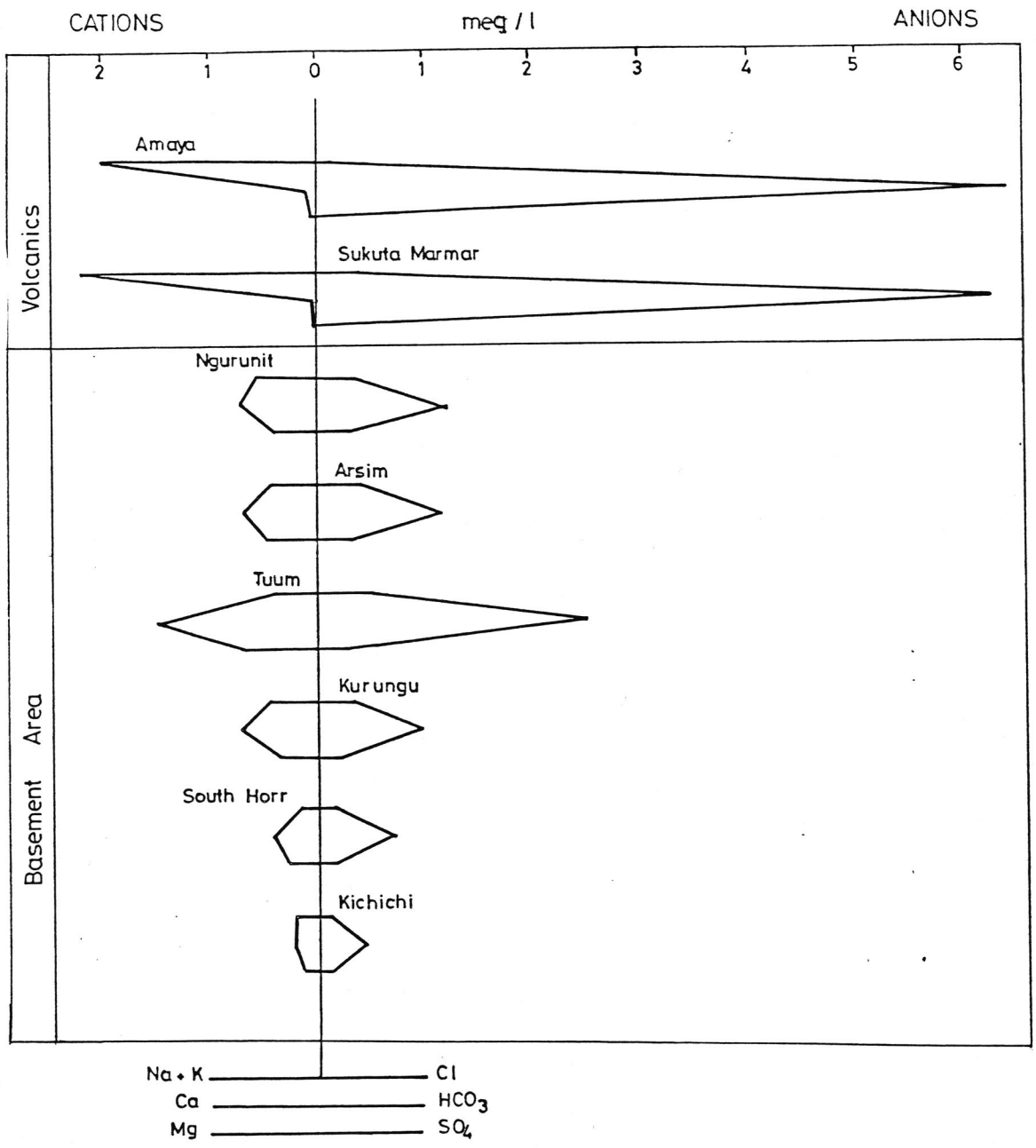


Fig. 5.2 Stiff Diagrams of Water Samples from Springs

5.7 The Local Aquifer System (Metamorphic Rock Area, Zone II)

5.7.1 General Description

This zone lies in the central and eastern part, covering about two-third of the District. As explained in Chapter 2, the Basement is a heterogenous mixture of rocks which have become metamorphic due to pressure and heat.

The mean annual rainfall varies between 1250 mm in the mountain ranges to only 200 mm in the eastern part of the District which is several times less than the corresponding potential evapotranspiration. Nevertheless, recharge occurs

(i) into the alluvial riverbeds whenever a lagga flows and from here into the underlying Basement rocks, and

(ii) during sporadic events when there is excess rainfall over a span of a few days allowing the soil to become saturated and subsequently recharge to the underlying bedrock.

The area can be characterized as undulating and low lying, interrupted by a few mountain ranges: the Matthews Range, the Karissia Hills, the Ndoto Mountain and the Ol Donyo Nyiro Range.

Groundwater storage of the Basement depends on

(i) weathered zones and

(ii) on fractures and faults which owe their origin to tectonic phenomena in the earth's crust.

Both weathered zones and open fractures can store water. Often they are correlated, notably in areas with pelitic rocks which decompose easily along cracks. But water storage in the granitic Basement almost solely depends on fractures: in such zones a system of interconnected open fractures is ideal for groundwater exploitation especially if it is traversed by laggas. In pelitic areas, such aquiferous properties are enhanced by weathering which is the very reason why prospects of finding water in pelitic areas are better. However, a very high grade of weathering can reduce permeability sharply. An example of such an situation is C7920, Kirisia.

The waterbearing zones are not hydraulically interconnected. So, there are many isolated aquifers in the Basement area and their aquiferous properties and water quality differ greatly from one place to another.

Sixty nine boreholes drilled within the metamorphic rock areas have so far been traced. Boreholes in these areas are generally low-to-moderately yielding . Water quality is usually poor. Some statistics are given below:

Table 5.9 Boreholes in Zone II

Number	Tested Yield (m^3/h)		Mean Levels (m below surface)		No. of dry holes	TDS (mg/l)	
	Mean	Range	Rest	Struck		Mean	Range
69	3.5	0 - 21.8	18	24	11	3116	335-17490

The total area of this zone is approximately 16,483 km2, and the average annual rainfall about 400 mm. Considering recharge at 1% and assuming that 20% of this as recoverable, about 13 million cubic metres of groundwater per year is available.

The average yield per borehole is around 3.5 m^3/hr. Therefore the above amount of water can be supplied by about 3000 boreholes assuming a pumping schedule of 12 hours per day.

The Basement rocks underlying the area can be subdivided into four broad units:

(i) Hard granitic and migmatitic metamorphic rocks,
(ii) Relatively soft pelitic and semi-pelitic metamorphic rocks
(iii) Undifferentiated metamorphic rocks, and
(iv) a much smaller unit underlain by intrusive granites.

This subdivision is partly based on observations by Shackleton (1946, see section 5.1) and partly based on the results from the drilling operations in Samburu, and was made possible through the recent geological mapping of Samburu. A complete set of reports and maps became only available during the first quarter of 1990. These units are described in section 5.7.3 (subzones IIa through IId).

Another classification based on geomorphology and superficial deposits was then superimposed on the previous one. This one has the following subzones:

(i) Basement area with sediment cover, (other than lagga deposits).
(ii) Basement with basalt caps
(iii) Basement mountain ranges and
(iv) Lagga deposits.

These eight units are described in the section 5.7.4 (subzones IIA through IID).

In order to investigate in a more quantitative way the aquiferous properties of these sub-units, the boreholes were classified according to the lithology of the first aquifer. The following classes could be distinguished:

(i) alluvium/colluvium underlain by Basement,
(ii) pelitic and semi-pelitic Basement,
(iii) granitic Basement
(iv) migmatitic Basement
(v) granitic intrusions

Fifteen boreholes could not be classified in this way because of(i) unclear, incomplete lithological logs or because (ii) the lithology did not corraborate with one of these classes. The result in terms of sample size, mean and standard deviation are shown in Table 5.11 where also the data for the Leroghi and Marti Plateau is shown.

Table 5.10 Borehole Yields in and Lithology

	Number	Mean	Standard Deviation
Intrusives	2	8.60	
Alluvium/Colluvium	18	6.50	5.94
Volcanic	8	3.87	3.46
Pelitic and semi-pelitic Basement	17	2.52	2.40
Granitic Basement	22	1.39	1.80
Migmatitic	2	0.60	

Frequency distributions of the three classes with sample sizes of around 20 are shown in Figure 5.3. It appears that the number of dry boreholes is around 30% for the granitic Basement Area and only around 6% (= one borehole only) in the pelitic area while yields are much lower in the granitic area given an equal probability level. Nevertheless, the differences become much smaller for the higher yields.

Tentatively, the following explanation is given:

(i) nearly every borehole in semi-pelitic basement strikes water. This suggests that this kind of basement is not completely impermeable because of many small cracks, weathered zones and possibly because of own nature. But large parts of the granitic basement are obviously completely impervious. However, a high degree of weathering has an adverse effect on borehole yield.

(ii) the frequency of occurrence of high yielding boreholes is almost the same in both areas. The source of water of these boreholes must be the major faults and fractures. This suggest that their effect does not vary much in either granitic or pelitic areas.

There are three dry boreholes in alluvium and colluvium. Two of these were drilled by WRAP. Drilling was stopped at a depth of around 80 m due to drilling problems. It is likely that there is groundwater underneath. If this is the case, the mean borehole yield for this area would be even a bit higher.

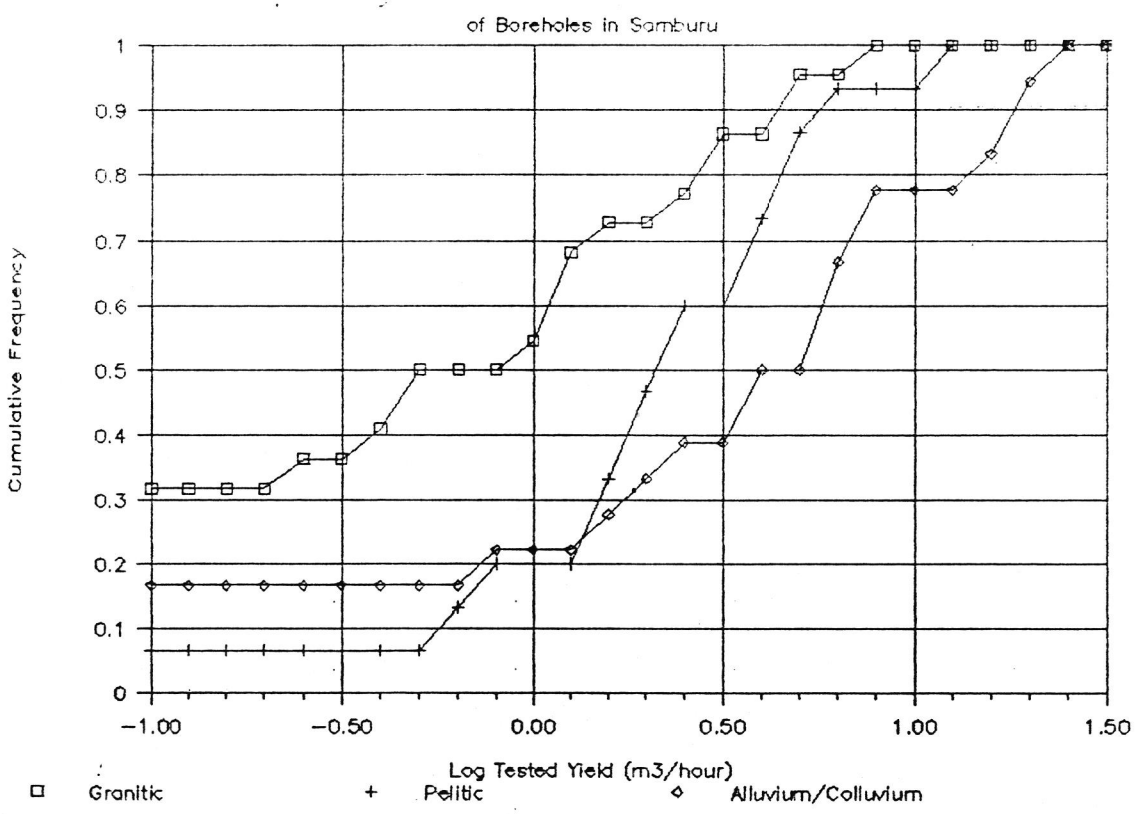


Figure 5.3 Frequency Distributions of Tested Yields

5.7.2 Testpumping Results

Of the nine tested boreholes in the Basement Area, seven draw water from Basement rocks while the two most productive holes (C7911 and C7918) have alluvium or colluvium as water bearing formations. The recovery of C7918 could be a textbook example while the recovery of the other borehole also behaves reasonable.

It is difficult to interpret the pumping tests of boreholes drilled in the bedrock properly as groundwater flow in Basement rocks is very different from flow in sedimentary rocks. Aquifers can be weathered zones and/or fracture systems of limited areal extent: it is even conceivable that the drilling process itself creates a fractured zone of limited extent.

The recoveries were used to estimate transmissibilities. But only few recoveries of boreholes drawing water from bedrock behave properly (e.g. C7914, C7915). All other graphs show moderate (e.g. C7908, C7917) to very sharp (e.g. C7910, C7916, C7919) changes of slope in the recovery. In these cases, it is not clear which part to use. Nevertheless, a conservative approach was adopted and transmissibilities were estimated using the steepest part of the recovery.

For the interpretation of the step drawdown part of the test and the procedure used to estimate the sustained yield, reference is made to Section 5.5.

5.7.3 Subzones - Classification According to Basement Units

Subzone IIa: The Pelitic and Semi-pelitic Areas

The pelitic and semi-pelitic area is mainly underlain by graphite gneisses and biotite gneisses. They tend to form the undulating plains. However the Ol Donyo Nyiro Range is largely made up of a hard type of biotite gneisses.

This subzone receives an average annual rainfall of about 400 mm, and this is the main source of groundwater recharge. Aquifers are found in the fractured and weathered zones of these metamorphic rocks. Transmissibilities in the order of 8 m2/day have been recorded. Water is struck at a depth of about 70 metres on average and the yields are low, averaging about 2.5 m3/hour. Water quality is generally poor with high amounts of dissolved solids and in some cases high fluoride concentrations.

Subzone IIb: The Granitic and Migmatitic Areas

The granitic and migmatitic area is mainly underlain by massive granitic and quarzofeldspatic gneisses, compact psammitic biotite gneisses, hornblende gneiss etc. These rocks are relatively hard and resistant to weathering and erosion. At various sections of these systems, the rocks are faulted, folded, fractured and sheared. They form the mountain ridges of the Ndoto Mountains, Karissia Hills and the Matthews Range and adjacent areas.

The annual rainfall in the area west of Mathews Range varies between 400 mm in the rolling plains to about 1250 mm in the mountains. But in the low lying, per-arid areas east of the Matthews Range, rainfall varies from 200 to 300 mm. The slopes are steep and rainwater runs down to the lower grounds while some of it is retained in the

fractured/sheared zones and fault zones. Some of the water that is held in the higher fracture/fault zones, is slowly discharged as springs.

The average water rest level is at 16.5 m but about 30% of the boreholes is dry. Yields are low and water quality bad except in narrow zones along laggas.

Yields from springs generally varies with the seasons. The available flow data on springs is given in Chapter 4. The quality of water from springs is good. Boreholes have not been drilled in these areas of high relief, but any borehole sunk outside faults or fractures is not expected to yield any water.

Subzone IIc: The Undivided Basement Area

Large areas around the El Barta plains could not be classified as either pelitic or granitic and were left undivided. These areas can best be considered as being underlain by layers of alternating granitic and semi-pelitic rocks.

Aquiferous properties will therefore be a mixture of those of subzones IIa and IIb.

Subzone IId: The Major Intrusives

Five Inselbergs consisting of massive pinkish granites are shown on the hydrogeological map. The central part of these granite mountains are impervious but moderately good aquifers can be found in the contact zones with the metamorphic rocks. This was demonstrated by borehole C7919 at Maseketa with a tested yield of 5.2 m^3/h.

5.7.4 Subzones - Classification According to Overlying Cover

Subzone IIA: Basement with Sediment Cover

Some local basins and river valleys are underlain by thick layers of sediments, locally more than 100 m thickness. They are either underlain by pelitic or granitic Basement. Sites with coarse-grained depositional material of sufficient thickness and enough drainage provide the best borehole sites in the District. But where groundwater drainage is insufficient, or even completely absent, saline water is likely to be the result.

The borehole records usually only indicate the alluvial nature of the aquifer, not whether the aquifer is a lagga deposit, alluvial fan, colluvium or whatever. Therefore, no differentiation could be made between these categories and the following statistics refer to all boreholes with unconsolidated superficial deposits.

From the available borehole data for this sub-zone, water struck levels are at an average of 11 metres below surface while the average yield is around $6m^3$/hour. For more details, reference is made to Figure 5.3.

Drilling by WRAP in this zone was not without problems and two attempts at the Kimaniki pass had to be abandoned at around 80 m depth, before the water table was struck.

Subzone IIB: Basement with Basalt caps

In the eastern part of Samburu District a number of isolated patches of thin basalt flows

overlie the metamorphic rocks. The main ones are the Marti Illaut, Marti ya Ampara, Errerr, Marti Serteta and Marti Nkangos. Except for Marti Serteta, all the rest are of small areal extent. These formations form blocks of plateau bounded by steep erosional escarpments rising to about 100 metres above the surrounding country. The basalt cap itself is about 6 metres thick.

Marti Serteta receives low rainfall, about 250 mm annual average. The other plateau areas receive no more than 400 mm. Surface drainage in these plateau is poor compared to the more closely spaced drainage patterns in the surrounding lowlands. Rain water either infiltrates or evaporates, rather than becoming streamflow. Where the drainage networks are better developed they are mainly consequent to slopes on the initial lava surfaces. On the southern part of Marti Serteta plateau a radial drainage pattern is developed around a cluster of relic volcanic centres.

Groundwater conditions in this plateau basalt subzone are expected to be determined by the underlying basement rocks. This implies that the aquiferous properties of the smaller basalt caps are bad. Their water bearing properties are probably the same as from small Basement mountains. But the areal extent of the Marti Serteta is so large that it can be considered a plain. The shrinkage cracks are probably favourable for infiltration and subsequent recharge as they impose surface runoff. Therefore, the water bearing properties of the Marti Serteta are likely to be better than from the surrounding area.

Subzone IIC: Mountain Ranges

There are four main mountain range areas that have been grouped under this subzone, namely the Oldoinyo Nyiru, the Ndoto Mountains, the Matthew Range and the Karisia Hills. These ranges form distinct physiographic features due to their high rise above the surrounding countryside.

The rocks are mainly massive granitoid gneisses or massive quartzofeldspatic gneisses while the Oldoinyo Nyiru is underlain by compact biotite gneisses. All these rocks have high resistance to erosion and weathering. The rocks are often faulted, folded, fractured and sheared.

Being areas of high relief, they experience the highest rainfall in the district. Over each of the four areas, the annual average rainfall ranges between 500 mm and 1250 mm.

The slopes are steep and rainwater runs down to the lower grounds while some is retained in the fractured/sheared zones and fault zones. Some of the water that is held in the higher fracture/fault zones is slowly discharged as springs.

Yields from springs generally varies with the seasons. The available flow data on springs is given in Chapter 4. The quality of water from springs is good. Boreholes have not been drilled in this subzone as these are mountain areas. However, any boreholes sunk outside faults or fractures is not expected to yield any water.

Subzone IID: The Lagga Sediments

All the main laggas in the metamorphic rock area are bordered by significant amounts of sandy and stony sediments. Groundwater occurs at shallow depth in these sediments. The groundwater levels rise steeply when the lagga begins to flow due to recharge and then subside slowly during the long periods of groundwater depletion by

evaporation and percolation.

The dug wells exploiting these lagga deposits are usually seasonal: often they are destroyed by the floods of the rainy season. Water is usually brought to the surface by rope-and-bucket. So, yields are low. In order to increase yields, they are often grouped together in well fields. Their construction is easy.

The groundwater quality in these lagga sediments is usually good, although bacteriological contamination is common in unprotected dug wells.

The total area for this subzone is approximately 310 km2. Using a conservative approach, seasonal abstractions are assumed to lower the waterlevel by 0.5 m. So, recharge during the next flood period can then be estimated at 50 mm given a porosity of 10%. So, approximately 18 million m3 of water is theoretically available from this subzone.

Assuming an average abstraction rate of 2 m3/hour per well, about 3000 dugwells can be sustained by these lagga deposits.

5.7.5 Chemical Composition of Groundwater in the Basement Area

The results of the chemical analyses are listed in Appendix 5.2 and 5.3.

By far the best water in the District comes from springs. These springs are usually situated in the mountain ranges where rainfall is high and the rocks predominantly granitic Basement. Mineralization is low: the mean TDS is 175 mg/l. Good chemical quality water can also be found in the hand dug wells situated in the dry river beds but unfortunately, their bacteriological quality is questionable.

Water quality of boreholes in the Basement Area is poor, especially if these boreholes are situated far away from laggas. The average TDS of samples of boreholes in the Basement Area (all boreholes listed in Appendix 5.3, except for the last two) amounts to 1460 mg/l with a maximum of 5184 and a minimum of 350 mg/l (this sample is from a borehole situated in alluvial deposits near a lagga). The W.H.O recommended maximum permissible limit of 1,500 mg/l in drinking water is exceeded in 6 cases out of 14 (43%) while the W.H.O recommend maximum permissible limit for fluoride of 2.5 mg/l is exceeded in one case only (7%).

When the individual concentrations of borehole samples are checked against the Drinking Water Standards for Kenya (Appendix 5.3) it turns out that eight out of 14(57%) samples are unsuitable for domestic use. But in the absence of other water supplies, it will be difficult to find better supplies.

Nearly all samples are suitable, or marginally suitable for cattle watering. Only one borehole in the Basement Area (Lodokojek, BH number unknown) produces water with a fluoride concentration of nearly 16 mg/l rendering it unsuitable for both dairy and beef cattle.

Spring water can be characterized as lowly mineralized water of the $CaHCO_3$ type. Groundwater is lagga deposits is probably of the same type while borehole water can be of any type (Figure 5.1 and 5.2)

6. WATER RESOURCES AVAILABILITY AND DEVELOPMENT POTENTIAL

6.1 General

Enough drinking water of acceptable chemical quality is available in most of the rural areas in Samburu: shallow wells can be dug in the alluvial deposits of most laggas. They usually strike groundwater at depths of less than 2 metres below the riverbed.

The occurrence of water in Samburu is controlled by topography, climatology and geology. As a result, water is unevenly distributed over the area.

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

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

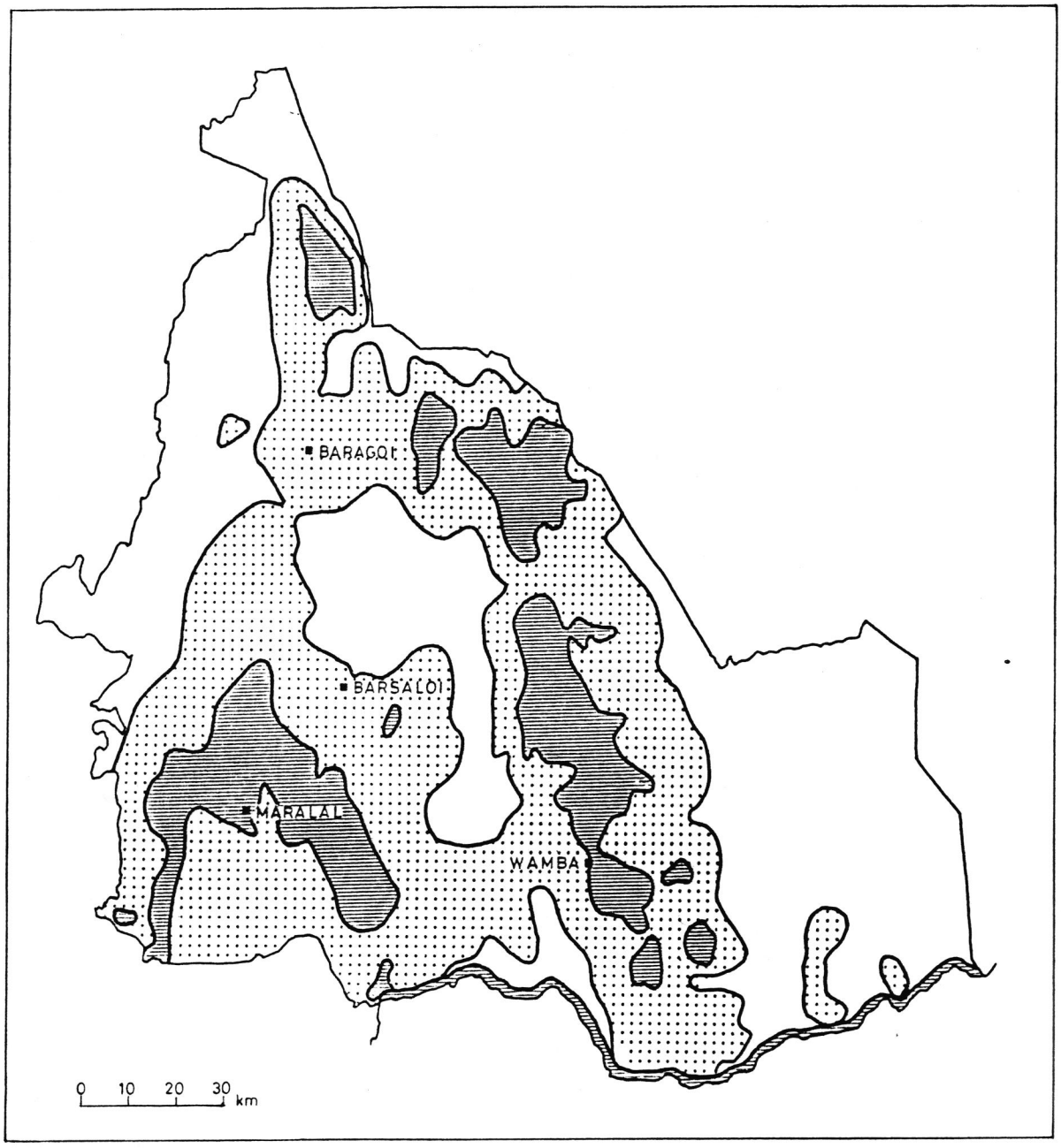
6.2 Previous studies

Dixey (1944, not available, but quoted by Humphrey & Sons, 1956)) recommended drilling of a large number of boreholes in Samburu to provide water to areas without permanent supplies in order to prolong the wet weather grazing. Unfortunately, successful drilling of deep boreholes turned out to be very costly and it was concluded in 1956 by H. Humphrey & Sons that reliance on other supplies such as dams and sub-surface dams was more economical.

All Geological Reports (1944 to present) contain at least one paragraph and in some cases two or three pages on the water resources of the respective areas of study. They have already been reviewed in Chapter 5.

In 1988, the Ministry of Water Development published a Progress Report on Water Resources Assessment Study in Samburu District (MoWD, 1988). This Report is now superseded by the present Report.

Bake (1989) carried out a short survey on the Water Resources in Samburu District using the afore mentioned Progress Report as the most important reference. His main recommendation is to improve maintenance of water sources: many "permanent" water sources are in fact "non-permanent" because of frequent breakdowns and very slow repairs of pumps etc, while catchments and dams are usually contaminated by cattle in the absence of proper fencing. Every dam should have an attendant to be in charge of the dam and to carry out repairs promptly.



Medium Availability	-	Median annual rainfall over 600 mm, perennial rivers and springs with very low dry season flows. Dams can hold water for a relatively longer time in dry periods.
Low to Medium Availability	-	Medium annual rainfall more than 400 but less than 600 mm; only laggas exist, low rainfall with high evaporation. Dams may not store water for long in prolonged drought.
Low Availability	-	Median annual rainfall less than 400 mm. Only laggas exist - offers very limited reliability of dams due to very low rainfall and very high evaporation.

Fig. 6.1 Surface Water Availability

6.3 Surface Water Availability

Streamflow amounts exceed groundwater flows, or even recharge by far: data from semi-arid areas in Baringo suggest that streamflow amounts to an estimated 5 % of the rainfall while groundwater recharge is estimated to be about 1 % of the rainfall.

As there are no data on streamflow in the laggas and only some data on flow durations, the Baringo run-off co-efficient can be used to estimate run-off from ungauged catchments. A runoff coefficient of 3 or 4% should be used as rainfall in Samburu is lower than in Baringo. The flow durations are also very important parameters to assess the surface water potential. Any area without permanent rivers should be classified as a low or medium potential area with respect to surface water. As there is only one major permanent stream (the Ewaso Ngiro) which has become semi-permanent in recent years because of upstream abstractions, no area with high surface water availability is present in the District. The few minor permanent streams at South Horr, Tum and Amaiya are very small.

The area where medium annual rainfall is lower than 400 mm is classified as of very low potential with respect to surface water availability. No permanent rivers rise in this area, only laggas. Dams offer little help because of low, unreliable flows combined with high evaporation. The area near Lake Turkana is also classified as area with very low availability because of the poor water quality.

The area where the mean annual rainfall falls between 400 and 600 mm is classified as an "area of low-to-medium surface water availability". Perennial rivers do not originate in this area: only laggas. Nevertheless, rainfall is such that dams may keep water, but in prolonged droughts they may dry up due to high evaporation losses.

Mean annual rainfall in the mountainous zones exceeds 600 mm. This area is classified "area of a medium surface water availability". A number of springs and perennial rivers originate in this zone. Dams, if properly designed, will seldom run dry.

The area bordering the Ewaso Ngiro cannot anymore be classified as high potential with respect to surface water because the river has become non-permanent in recent years due to increased abstractions in the upper reaches during droughts. It has dried up along a stretch of about 50 km upstream of Archer's Post in 1985 and 1986 for the first time in living memory. But because water is available most of the time, this stretch is classified as medium availability.

6.4 Groundwater Availability

6.4.1 General Situation

The total amount of groundwater which is annually replenished has been estimated to be in the range of 100 Mln m^3 (Chapter 5). But the amount of water which can be abstracted is considerably lower.

If a large part of the recharge was abstracted, groundwater levels would fall and many boreholes would dry up, thus making high investments worthless. Nevertheless, safe yield can be estimated at around 20 % of the recharge from rainfall. Thus, a preliminary estimate of the maximum density of waterpoints for the district can be made as follows:

average rainfall: 500 mm/year, recharge: 1 %, pumping rate: 3.8 m3/hour during 12 hours a day. In such a situation 13 km² is enough to sustain one waterpoint. So, the waterpoint density is one per 13 km², or for Samburu District with an area of around 20,000 km², around 1500 boreholes can be envisaged with a total annual yield of around 20 mln m²/year. This exceeds the total expected water demand of around 17.5 mln m²/year in the year 2013 (see .....).

However, the values quoted above are averages. The areal distribution of groundwater is highly irregular both quantitatively and qualitatively. Strong variations in water quality also contribute to the uneven distribution of suitable groundwater: the quality in only 20% of the sampled boreholes is suitable for domestic purposes according to the WHO standards for drinking water. This is mainly due to high salinity and high fluoride. But if these standards are relaxed to TDS < 2000 ppm and Fl < 2.0 ppm, 70 % of the samples can be classified as suitable for domestic use.

A groundwater availability map is prepared and shown as Plate 6.1. On this map, Samburu District is subdivided into five zones with respectively (i) medium-to-high and (ii) medium (iii) low-to-medium, (iv) low and (v) very low potential. Their groundwater availability is summarized in Table 6.3. High potential areas such as defined for Baringo and Laikipia District do not occur in Samburu District.

Table 6.3 Groundwater Availability

GROUNDWATER AVAILABILITY	DESCRIPTION	TESTED YIELD	WATER LEVEL		QUALITY
		Mean m³/h	Struck m	Rest m	
Medium-to-High ca 310 Km²	Alluvial Deposits along main laggas	0.5-3.0	0-2	0-2	good
Medium 1482 Km²	Contact Zone Intrusives	9	11	6	fair
	Plateau Phonolites	4	80	50	good (TDS≈500) though high fluoride occurs
Low-to-Medium 13625 Km²	Pelitic Basement	2.5	40	30	variable but mostly bad TDS≈3000 mg/l
	Undivided Basement				
	Granitic } Basement Migmatitic }	1.4	24	16 (but 30% dry)	TDS: 300-18000 mg/l
Low 2845 Km²	Western Strip Volcanics	no data	very deep	deep	no data but probably acceptable
Very Low 2548 Km²	Mountain Ranges 1264 Km²	very low	very deep	very deep	good
	Inselbergs 964 Km²	very low	very deep	very deep	-
	Small Plateau Basalts Areas 320 Km²	no data	very deep	very deep	-

6.4.2 Areas of Medium-to-High Groundwater Availability

Alluvial Deposits along the main Laggas

There is a considerable amount of groundwater in the sandy alluvial deposits along the laggas despite their limited areal extent. Often these alluvial fills are more than one km wide, and although the thickness is not known, it could locally exceed 10 metres, even up to 100 m was reported by the geophysical team. They are usually underlain by Basement, and rarely by Volcanics.

Recharge of these alluvial aquifers takes usually place during first streamflow producing rainstorms of both the short and long rains. During the rest of the rainy seasons, these aquifers remain usually fully recharged. Leakage to (=recharge) the underlying rocks continues throughout the year. Therefore, the underlying and adjacent formations are more promising than equivalent formations elsewhere. In addition, the Basement underneath laggas could have better aquiferous properties than elsewhere as laggas tend to follow fractured and faulted zones of pelitic Basement.

Groundwater levels are usually very shallow: in the riverbed itself they vary between zero and one or two metres while underneath the riverbanks groundwater is a bit deeper. Seasonal fluctuations vary between one and two metres underneath the riverbeds to a few decimetres under the riverbanks. These fluctuations reflect both consumptive use by vegetation and leakage to the underlying bedrock.

There are probably several hundreds of seasonal wells in these laggas: dug after each rainy season, most of them are destroyed by the floods at the beginning of the next season.

Groundwater quality is good although bacteriological contamination is likely as livestock in great numbers is watered at these points. But the quality often deteriorates rapidly when moving away from the lagga.

6.4.3 Areas of Medium Groundwater Availability

Leroghi and Marti Plateau

The Leroghi and Marti Plateaux are underlain by rather undisturbed phonolites. To the East, these Plateau Lavas wedge out against the Basement Rocks while the Rift Valley shoulder is the western boundary. As these rocks are volcanics, a regional aquifer system can be expected: there are extensive aquifers of old landsurfaces and cinder layers, which are interconnected by fractures and faults. Although the number of boreholes is too small and their areal distribution inadequate to prove the regionality, evidence from similar areas in Laikipia and Meru clearly shows the existence of a regional aquifer systems in volcanics.

Rainfall is relatively high (around 600 mm in Leroghi and around 500 mm at Marti) and recharge relatively high because of the nature of the rocks and the morphology. Although elsewhere phonolites are known to have poor aquiferous properties, the Leroghi and Poror phonolites are an exception on this rule.

Borehole yields do not differ strongly from those in the Basement Area although the sample is much smaller (6 against 82). The average is 3.9, the minimum is 0.7 and the maximum is 12. Water struck levels vary between 26 and 170 metres. Water rest levels vary between one and 150 m with a mean of around 50 m.

Groundwater quality is mildly saline and soft. But fluoride levels can sometimes exceed the permitted levels.

Contact Zone Intrusives

The contact zones around the granitic intrusives are areas where boreholes yield a lot of water. The WRAP borehole at Masikita has a tested yield of around 5 m^2/h. Water quality is fair to good.

Note that only the contact zone has a medium groundwater availability. Waterbearing properties deteriorate rapidly towards the centre of those intrusives because (i) the granites become increasingly massive and because of the geomorphology: (ii) the intrusives can usually be recognised in the field as dome-shaped mountains

6.4.4 Areas of Low-to-Medium Groundwater Availability

Pelitic, Granitic and Migmatitic Basement

This area is either directly underlain by the metamorphic rocks of the Basement System, or underlain by alluvial or colluvial deposits covering Basement Rocks. Also included in this area are the outcrops of major Plateau Basalts in the eastern part of the District. As the thickness of these Basalts is usually less than 15 metres, their aquiferous properties are mainly determined by the underlying Basement. Excluded are the mountain ranges, Inselbergs and small patches of Plateau Basalts which are rated as having very low groundwater availability (Section 6.4.3.6).

In the valleys, groundwater potential is relatively good. Most of these valleys are underlain by softer, pelitic Basement where deep subsurface decay can produce thick zones of reasonably permeably material. This is in contrast to the mountain ranges where the dominant rock type is the more resistant massive granitic type of Basement. The higher rainfall in these mountainous areas seems not to outweigh the adverse rock properties. Groundwater availability in areas underlain by predominantly pelitic and semi-pelitic rocks are considered to be in top of the range while the areas with predominantly granitic and migmatitic rocks are in the lower end of the range. Major parts, notably the granitic and migmatitic high grounds, do not contain water in recoverable quantities. The areal extent of these two types of Basement Rocks is indicated on Plate 5.1.

The region as a whole is classified as having low-to-medium groundwater availability on two grounds: (i) because of the low rainfall and high evapotranspiration in the lowlands, and consequently, the low recharge, and (ii) because of the local nature of the waterbearing zones. But tested yields are not too bad: those in pelitic and semi-pelitic Basement are clearly higher (around 2.5 m3/hour) than the same in granitic and migmatitic areas (around 1.5 m3/h) with a failure rate of about 30%.

Note that small granitic/migmatitic zones occur frequently in the pelitic and semi-pelitic zone, and the other way round. The best places to sink boreholes are definitely those with lots of well developed faults and fractures. In such areas, the best conditions for groundwater recovery prevail as far down the valleys as possible.

Often, water quality is not good enough for domestic use or cattle watering, but in the absence of alternatives, the water is used by the people and their cattle. Salinity values are often too high for domestic use (ca 90%) and even for cattle watering (ca 10%). The quality of the groundwater in the Basement rocks can be characterized as varying between mildly saline (TDS 500 ppm in Amaiya, Wamba and the northern area) to very saline (TDS 1400 to 2000 ppm in Maralal, Kisima, Lodungokwe, Lerata, Serolipi, and even around 5000 ppm in Suari) and hard to very hard (200 ppm to 700 ppm). Fluoride concentrations often exceed 2.0 mg/l (ca 40%).

For a summary of the relevant hydrogeological properties reference is made to Table 6.3. Frequency distributions of tested yields are shown in Figure 5.3.

6.4.5 Areas of Low Groundwater Availability

Western Strip Volcanics

There are no boreholes in this area, mainly because of its inaccessibility. So the conclusions presented are based on similar areas in the Laikipia and Baringo Districts (WRAP, 1987 a and b) although information in these areas was also scarce.

The area is bordered to the East by the Rift Valley shoulder and to the West by the western boundary of the District, which roughly coincides with the Rift Valley floor. It is underlain by volcanics which are thoroughly broken up by major stepfaults, and lots of fractures. It is underlain by mainly basalts, trachytes and tuffs. The main direction of groundwater flow is towards the west, towards the Rift Valley. Because rainfall is low, groundwater levels could be even deeper than in similar areas in Lakipia where water struck levels were locally found at more than 240 m depth!

Based on the similarity, depths to water struck level are expected to be high as are the expected depths to water rest level. But borehole yields could be quite good. It is expected that groundwater is suitable for domestic use and irrigation although the occurrence of local spots of high fluoride concentrations along the faults is likely. But because of the much lower rainfall, all aquiferous properties are likely to be more unfavourable than in similar areas in Laikipia and Baringo.

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

Groundwater quality is expected to be worse than below the Leroghi Plateau where it is mildly saline and soft. Fluoride concentrations are expected to exceed the permitted levels rather often.

Taking into account the inaccessibility of the area, the great depth to the groundwater table, the low rainfall, the expected low potential, it is questionable whether any groundwater development can be justified in the foreseeable future.

6.4.6 Area of Very Low Groundwater Availability

Mountain Ranges, Inselbergs and Small Plateau Basalts

These are areas within the Basement Country where geomorphology and geology conditions have an adverse effect on the groundwater availability. Height plays an important role as a reason to classify these areas as having a very low groundwater availability, but the nature of the predominant rocks in the mountain ranges and Inselbergs plays another important role: most rocks are massive quarzofeldspatic gneisses and migmatites which have poor waterbearing properties.

No quantitative data are available as no boreholes have been drilled into the rocks underlying these units. Even in the absence of borehole data, any other area in Samburu looks more promising.

6.5 Water Resources Development Potential

6.5.1 Surface Water Development Potential

The opportunities for water development are discussed in detail in the Planning Reports (WRAP, 1989). Here, only broad outline is given of the development potential.

The major problem in surface water development is the water distribution in time and space: most of the streams are ephemeral. So, storage facilities are required to bridge dry spells. This study concentrates on small scale development. Nevertheless, there are suitable sites for large dams along the gorge of the Ewaso Ngiro (e.g. Grid Ref. 2793 o836). The following only contains a number of small-scale, cost-effective water development opportunities.

Along the perennial part of the Ewaso Ngiro, construction of streamflow intakes for irrigation can be considered. All other perennial streams have very small flows during the dry seasons. Construction of intakes along any other river seems not to be cost-effective.

In the rest of the area, subsurface dams and sand-filled dams built in the riverbeds of ephemeral streams may provide additional storage capacity (in addition the natural storage capacity of riverbeds).

Pans and earth dams are another important method of water development in the semi-arid parts of Kenya. Site selection is very important as the sub-soil must be impermeable to avoid seepage. Pans are primarily intended for livestock watering. The direct use of water from these sources for human consumption is not recommended because of the pollution hazards.

Roof catchments can be an important supplementary source of drinking water provided that the storage tank is properly constructed.

Application of any of these methods depends on detailed site investigations and cost analysis. This has been done by the WRAP Planning section. In these reports, investment packages have been developed for each sublocation.

6.5.2 Groundwater Development Potential

Surface water is scarce in Samburu District, except along the banks of the perennial part of the Ewaso Ngiro. Groundwater is the only permanent source of water in most of the district, and the safest source by far. So, even where abundant surface water supplies are available, construction of boreholes and shallow wells should be considered, particularly for domestic supplies: though development of groundwater is not cheap, the benefits in the form of the supply being permanent and reduced incidence of illnesses certainly outweigh high initial costs. Although development of a large number of permanent watering points for livestock is feasible from the resources point of view, uncontrolled development could be detrimental for the ecological balance of the District.

Medium-to-High Potential Areas

Alluvial Deposits along the main Laggas

This area mainly consists of irregularly shaped elongated strips of alluvial deposits along the major laggas and their underlying bedrock. Although few data are available, its width locally exceeds 1 km. Thickness of the alluvial aquifer exceeds locally 10 m, even values of 100 m are reported. Although yields from individual wells in the alluvium are not very high (0.5 - 3.0 m^2/h, although even 7 m^2/h is reported), wells can probably be closely spaced. Recharge of the alluvial aquifers takes place twice yearly, during both the short and long rains while the underlying and adjacent bedrock is recharged from the overlying alluvium throughout the year, or until the alluvium is completely drained. During the dry seasons in between the rains, most groundwater can be abstracted from the alluvial aquifers. In contrast to elsewhere in Samburu, the alluvial aquifers along laggas can be emptied during the dry seasons: the more water is abstracted from these aquifers, the higher is the recharge during the following rainy season. The main reason to classify these areas as medium potential instead of high potential, is that the average thickness of the alluvial deposits is expected to be low, a few metres only. The chemical quality of the groundwater in the alluvium is probably the best in the District, but quality usually deteriorates rapidly when moving away from the laggas.

Traditionally, pastoralists obtained their water during dry seasons from the lagga deposits. A hole of one or two metres deep is usually enough. This source could be further developed by construction of subsurface dams and sand-filled dams in the riverbeds of ephemeral streams thus providing additional storage capacity (in addition to the natural storage capacity of riverbeds).

Medium Potential Areas

Leroghi and Marti Plateau

This is a volcanic area with a rainfall of around 600 mm. In such aquifers, the success rate of boreholes is high while only few boreholes will have unacceptable chemical quality. Unacceptable quality is usually due to high fluoride concentrations. Borehole siting is not necessary as groundwater is nearly always struck. Despite the phonolitic nature of the aquifers, boreholes have rather high yields. Small scale irrigation (e.g. of kitchen gardens) is possible.

Low-to-Medium Potential Areas

Basement Area

As aquifers in the Basement Area are isolated, it is very important to find the right sites (Chapter 5). These aquifers can be characterized as irregularly shaped waterbearing cells. Recharge often comes from laggas, or possibly rainfall. Given the size of the Basement Area, there seems to be room for at least several hundreds of boreholes. But experience shows that a success rate of approximately 70 % only can be expected: 20 % dry and around 10 % chemically unsuitable for cattle (and humans).

Groundwater development for irrigation can be excluded because of the low yields.

Low Potential Areas

Western Strip Volcanics

This area is heavily faulted and fractured. No boreholes have been drilled. Annual rainfall is low ranging between 200 and 500 mm. In similar areas in Laikipia (but with annual rainfalls of around 800 mm) potential was classified as medium or variable. Even so, water struck levels were locally at around 240 m below the ground surface although water rest levels were usually at less than 100 m. But in the Samburu part of the Eastern Rift Valley shoulder, the situation is definitely worse. It is highly questionable whether any groundwater development whatsoever in this area is justified at all. In addition, the area is rather inaccessible.

Very Low Potential Areas

Mountain Ranges and Inselbergs

These areas have in common that they are standing high above the plains and that the aquifers underlying these areas are Basement Rocks. They are made up of predominantly massive quarzo-fieldspatic gneisses or biotitic gneisses with adverse waterbearing properties. In addition, most of these areas are game and forest reserves. Development of groundwater resources, if any, is not justified.

Small Plateau Basalt Areas

These are small table-mountains, capped with thin lavaflows of around 10 metres thickness which rise 100 or 200 m above the plains. As the waterbearing properties of these rocks are determined by the underlying Basement Rocks and not by the thin lava blanket, it is clear that groundwater resources at reasonable depth are lacking and that attempts to develop these resources are not justified.

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